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"Strengthening Capacities to Enhance Coordinated and Integrated Disaster Risk Reduction Actions and Adaptation to Climate Change in Agriculture in the Northern Mountain Regions of Viet Nam"

Hazard, Vulnerability and Risk Mapping in Lao Cai, Yen Bai and Phu Tho provinces

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Executive summary

The assessment and mapping of hazards, local vulnerability and risks in Phu Tho, Yen Bai and Lao Cai Provinces was undertaken in the context of the UNJPVIE037UNJ (Strengthening Capacities to Enhance Coordinated and Integrated Disaster Risk Reduction Actions and Adaptation to Climate Change in Agriculture in the Northern Mountain Regions of Viet Nam) Project, which has been implemented since March 2010. The project is implemented by the Ministries of Agriculture and Rural Development (MARD) and the three involved provincial departments and executed by FAO and NOMAFSI, with funding from the One UN program.

MARD did not fully approved and therefore implemented the project until June 2010. The delay in project endorsement caused to the team difficulties in working at provincial level during the first part of 2010. Provincial authorities were not informed from national government and data release was impossible. Anyway the team carried out between March and April 2010 part of the activities in two provinces (Yen Bai and Lao Cai): focus group meetings and visits and validation of data and map in provincial and district offices.

Therefore, even the ROs officially start the activities in March, the implementation of the activities of risk mapping could not start before than October 2010, causing the delay in the team's work flow and the inability to follow the established workplan.

The general scheme implemented in this project follow the model that predicts to compute the risk level as a function of hazard pressure (H) multiplied the level of the local vulnerability (V). The vulnerability itself can be divided in two main component: the sensitivity (S) and the adaptive capacity (AC) or resilience of the community to the hazards. The general equation for a generic hazard "i" can be wrote as:

$$R_{hi} = H_i * V = H_i * S / AC$$

Finally, the overall multi hazard risk level was calculated as the summation of all hazard specific risk.

The list of hazard impacting the study area was developed during focus group meeting, resulting in seven main kind of hazardous phenomena: flooding, flash flood, landslide, wildfire, drought, lao wind and frost. The computation of sensitivity was based on the population density and agriculture resources density. Finally the adaptive capacity was assessed according to the framework adopted by Smit et al. (2001), reviewed and adapted to the Vietnamese situation. Such scheme was used to drive the discussion in the focus group meeting. Among several methodologies and scheme to calculate weight for the indicator and the different component, e adopt the Analytical Hierarchical Process (AHP) to define the relative importance of the hazard and the different component of adaptive capacity.

The people will use the final tool (maps) are heterogeneous for education and work in a poor setting environment. Therefore the idea behind the decision is to create a tool simple to manage without any complication.

Abbreviations

AC_ECON	Economic Adaptive Capacity Index
AC_INFR	Infrastructure Adaptive Capacity Index
AC_INST	Institutional Adaptive Capacity Index
AC_NATU	Natural Adaptive Capacity Index
AC_SOCI	Social Adaptive Capacity Index
AHP	Analytic Hierarchy Process
ALAI	Agriculture Land Availability Index
ALDI	Agriculture Land Density Index
AMAI	Annual Mean Aridity Index
AMS	American Meteorological Society
ARI	Alphabetization Ration Index
ASPECT	Aspcet (degree direction to North)
ASTER	Advanced Spaceborn Thermal Emission and Reflection
ASYI	Average Schooling Years Index
CAD	Computer Aided Design software
CCA	Climate Change Adaption
CFSC	Committee for Flood and Storm Control
CFSCCI	Committee for Flood and Storm Control Capacity Index
CIFOR	Centre International Forestry Research
CRU	Climatic Research Unit (University of East Anglia)
CVI	Climatic Variability Index
DARD	Department of Agriculture and Rural Development
DONRE	Department Of Natural Resources and Environment
DEM	Digital Elevation Model
DRR	Disaster Risk Reduction
EDPI	Emergency Drills Participation Index
EEPSEA	Economy and Environment Program of South East Asia
EHI	Electricity House Index
ELEVAT	Elevation
EPI	Elder People Index
ETMIPE	Ethnic Minority Density Index
FAO	Food and Agriculture Organization
FIPI	Forest Inventory and Planning Institute
FLI	Flat Land Index
FORCOV	Forest Coverage Density for flash flood
FOREST	Forest density index for drought
FRSFRE	Frost day frequency
FSI	Family Size Index
FUEL	Vegetable Fuel Concentration Index
GDP	Gross Domestic Product
GIS	Geographic Information System

GRI	Gender Ration Index
GSO	General Statistic Office
H_DROUG	Drought Hazard Index
H_FLASH	Flash Flood Hazard Index
H_FROST	Frost Hazard Index
H_LAOWI	Lao Wind Hazard Index
H_WILDF	Wildfire Hazard Index
HQI	House Quality Index
IFRC	International Federation of Red Cross and Red Crescent society
IMH	Institute of Meteorology and Hydrology
IPCC	Intergovernmental Panel on Climate Change
LANCOV	Land Cover Type for flash flood
LCI	Leader Capacity Index
MARD	Ministry of Agriculture and Rural Development
NASA	National Aeronautics and Space Administration
NGO	Non Governmental Organization
NOMAFSI	North Mountain Agriculture and Forestry Science Institute
ONE UN	Reform program of United Nation agencies in a country
PAPH	Percentage of Almost Permanent House
PBI	Public Building Index
PBWH	Percentage of Brick-stone Wall House
PCI	Precipitation Concentration Index
PCRH	Percentage of Concrete Roof House
PDI	Population Density Index
PEMI	Percentage of Ethnic Minority Index
PHI	Poor Housing Index
PHSTI	Percentage of House with Septic Toilette Inside
PHTW	Percentage of House with Tape Water
PMB	Project Management Board
PNFLAI	Protected and Natural Forest Land Availability Index
PPH	Percentage of Permanent House
PSPH	Percentage of Semi Permanent House
PWH	Percentage of Weak House
RDI	Road Density Index
RHLHUM	Relative Humidity
RIVDIS	River distance Index
RMPI	Risk Management Plan Index
ROADIS	Road Distance Index
RSDI	Railway Station Distance Index
SENSIT	Sensitivity Index
SETDIS	Settlement Distance Index
SLOPPY	Slope (degree)
SPI	Standardized Precipitation Index

TAR	Third Assessment Report of the International Panel of Climate Change
TMPTMX	Maximum temperature
TWTI	Tape Water Toilette Index
UN	United Nation
UNDP	United Nation Development Program
UNEP	United Nation Environmental Program
UPI	Underage People Index
URI	Unemployed Rate Index
UTM	Universal Transverse Mercator coordinate system
WGS84	World Geodetic System (Datum 1984)
WMO	World Meteorological Organization

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1. Introduction

1.1. Background

The natural system ruled the Earth for millions of years before the appearance of Homo sapiens on our planet. Many geophysical natural hazards as earthquakes, volcanic eruptions, land sliding, and/or flooding occurred and posing danger only the prevailing flora and fauna. Millions of years later, the human presence changed the geophysical events into natural disasters.

Natural hazards have the property of threatening the different social entities of the Earth, nevertheless, this threat is not only the result of the process per se (natural sensitivity), and it is the result of the human systems and their associated sensitivity towards them (human sensitivity). When both types of sensitivity have the same spatial and temporal coordinates, natural disasters can take place.

Natural disasters occur worldwide; however, their impact is greater in developing countries, where they happen often. Viet Nam is one of the countries in the Asia Pacific region most prone to natural disasters due to its geographic position and topographic condition. Its long coastline is exposed to annual beating by six to ten typhoons and tropical depressions, generated in the Western North Pacific Ocean (UNDP, 2000a). Such events cause heavy rains and flooding. Opposite, the Viet Nam's mountain regions is hit alternatively by flash floods and prolonged drought which lead to wild fires (UNDP, 2000b).

Climate change is leading to increase the frequency of natural hazards and consequently natural disasters. Climate change is expected to induce a temperature rise up and alteration of rainfall patterns. Indeed, the annual average temperature during the last period (1950 - 2000) increased by 0.7°C (UNDP, 2000a). The Country may expect an increase of rainfall of 20 % during the Northeast monsoon, while the river flow in the dry season may be reduced to 40 %, causing severe water scarcity (IMH, 2005).

Floods and typhoons have been a constant threat to the life and productivity of the Vietnamese people. Currently, 70% of the 73 million people of Vietnam live in disaster-prone areas (Shaw, 2006). These people's lives and livelihoods very much depend on the country's natural resources. Losing crops and homes in floods and storms keeps many rural Vietnamese trapped in a cycle of poverty. The agriculture activities (employing 57 % of the total labour force) are highly exposed to recurring natural hazards especially in most impacted areas including northern mountain region. In recent years, disaster occurred in mountainous areas with increasingly unprecedented severity and scale, devastating small watersheds, causing serious losses in term of human lives, properties and ecological environment (National report on disaster reduction in Vietnam, 2005). The year 2008 has been one of the worst in terms of impacts of storms and floods. During August 2008 tropical storm Kammuri caused severe damages in North Viet Nam, particularly in Phu Tho, Yen Bai and Lao Cai Provinces. Floods in mid-November resulted in loss of 208,719 ha of rice and extensive irrigation infrastructures. The economic losses exceed USD 430 million (IFRC, 2008).

Within the ONE UN plan, UN agencies are committed to support Ministry of Agriculture and Rural Development (MARD) of Viet Nam in disaster risk reduction, preparedness and response. In particularly FAO (Food and Alcohol Organization), is the responsible UN agencies for Agriculture and Food Security. Within this context, FAO, MARD and its technical departments have developed a pilot project for Disaster Risk Reduction (DRR) and Climate Change Adaption (CCA) to support the most vulnerable communities affected by recurrent climate related risks in three provinces of the Northern Mountain Regions: Phu Tho, Yen Bai and Lao Cai.

A well coordinated DRR and CCA program need to start addressing existing hazard, vulnerabilities and risks in the local community. Availability of specific data on disaster impacts and indicator of local vulnerability in a GIS database provides the basis to understand the issues and make better informed decisions in disaster preparedness, response and long term adaptive measures. The spatial information products with details of local vulnerabilities, risks and natural resource endowment is being considered as an effective decision making tool for risk management planning. Such decision support tools also will be useful to enhance the sustainability of natural resources exploitation through a better plan of the land use and the development of alternatives and adaptation's measures in the northern mountain region.

The here presented activity address the need that every country or part of it has: define a rank of importance of its hazards and risks in the terms of likelihood of their occurrence and the severity of their impacts on the people, infrastructure and ecosystems. As a matter of fact, no country can face all their risks of hazards at the same time, therefore the reaction measures have to be implemented in parts, with the highest priorities given to the protection of the "hotspots", that will go to map and highlight.

We select the factors or determinants of hazard, vulnerability and adaptive capacity (with local stakeholder inputs), obtain measures on these (mainly from available secondary data), adopt an aggregation function over the measures (generally summation) and calculate an overall risk value for each elementary "cell" (commune) of the system (province). The analyses involved comparative evaluation or rating based on criteria, indices and variables typically selected by the researchers (Van der Veen and Logtmeijer, 2005; O'Brien et al., 2004; Kelly and Adger, 2000; Adger et al., 2004; Brooks et al., 2005; Rayner and Malone, 2001) through a participatory mechanism with the local stakeholders. Thus, surrogate measures will be estimated and then aggregated to generate an overall risk ''score'' (or level or rating) for each system (Adger, 2006). The main purpose is to provide an evaluation of the relative risk of the commune within a district, or the province or the whole study area.

This research does not aim to identify the processes, determinants or drivers of adaptive capacity and vulnerability as they function in each system; they are taken as given, and used as the basis for the rating or ranking analysis of the elementary elements of the studied area.

1.1.1. Target provinces

Phu Tho province is located from 20° 55' to 21° 43' North latitude and from 104° 46' to 105° 24' East longitude, at the apex of the Red River Delta, 80 Km Northwest of Hanoi. It is a joining point between eastern-north, the Red River Delta and the western-north region. With such position, Phu Tho is considered as the North gate to Ha Noi capital and is it one of the important economic regions in the North Viet Nam. The Phu Tho province's total area is about 3,500 Km^2 and the population reach about 1,300,000, of which rural population accounts for 85 %. The province is divided in 11 districts and two township areas, with 270 communes and wards of which 214 are in mountain minority areas.

According to its topography, Phu Tho may be divided into 3 main sub-regions: (a) The southern and western mountain sub-region (64 % of total area) at an average height of 200m - 500m above the sea level. (b) The midland sub-region that has a topography with low hills and mounds of 50m - 200m intermixing with field's slopes. (c) The delta sub-region, including Viet Tri city, that is an ancient alluvial soil and field along the rivers including some areas with low mounds, fairy even and flat terrain.

Yen Bai is a mountain province with an area of about 6,900 Km^2 and a population of about 750,000. It is located from 21° 18' to 22° 16' North latitude and from 103° 54' to 105° 5' East longitude. Yen Bai City is the provincial capital. The province is divided in 7 districts and two township areas, with 180 communes and wards.

Yen Bai is characterized by high terrain gradually from southeast to northwest and by three major mountain ranges running in direction Northwest - Southeast. The topography is quite complex but can be divided into two major areas: the high and low areas. The West part area is sparsely populated, with high average elevation (over 600 m) accounting for 67 % of the province's surface. The East part of the province is characterized by lower elevations (below 600 m) and includes low hills (on the left bank of Red river), the Red river valley basin and an artificial lake with a surface of 20,000 hectares.

Lao Cai is a mountainous border province, that extends from21° 40' to 22° 49' North latitude and from 103° 31' to 104° 36' East longitude and it is situated 350 Km from Hanoi. The province covers an area of about 6,400 km^2. The border with China (Yunnan province) has an extension of 203 km. The total provincial population account about 600,000 people, including 25 ethnic groups (about 64 % of total population across the province). Administrative Lao Cai province is divided into 8 districts and the township of Lao Cai City.

Topography of Lao Cai is very complex, with high mountains range that divided several valley lowlands, to create different climatic zones. The South West part of the province is occupied by a plateau between 600 and 1,100 m. The highest point is Mount Fansipan on Hoang Lien Son range with an elevation of 3,143 m above the sea.

1.2. Outcome Risk model and definition of the terms

The scientific literature system produced a large array of terms: vulnerability, sensitivity, resilience, adaptation, adaptive capacity, risk, hazard, coping range, adaptation baseline and so on (IPCC, 2001; Adger et al., 2002; Burton et al., 2002, and many others). The definition and relationships between these terms are often unclear, and the same term may have different meanings when used from different scholarly communities and by different authors. Mainly the "conflict" is played on the vulnerability concept. As a matter of fact, large debate is dedicated to the definition of vulnerability and its relationship with the other components. Definitions of vulnerability in the climate change related literature tend to fall into two categories, viewing vulnerability either (i) in terms of the amount of (potential) damage caused to a system by a particular climate-related event or hazard (Jones and Boer, 2003), or (ii) as a state that exists within a system before it encounters a hazard event (Allen, 2003). The reason behind such controversial is that two different approach are used in disasters and climate change management work.

The former see the vulnerability of a human system as determined by the nature of the physical hazard(s) to which it is exposed, the likelihood or frequency of occurrence of the hazard(s), the extent of human exposure to hazard, and the system's sensitivity to the impacts of the hazard(s), called outcome risk or Biophysical Vulnerability (Brooks, 2003) and measure it in terms of amount of damage. This approach downplayed or neglected the role of human systems in mediating with natural hazards and it has focused on human exposure to hazard rather than on the ability of people to cope with hazards once they occur. "Vulnerability is measured by indicators such as monetary cost, human mortality, production costs, [or] ecosystem damage…" (Jones and Boer, 2003) experienced by a system as a result of an encounter with a hazard. These are indicators of outcome rather than indicators of the state of a system.

Conversely, the second approach see the vulnerability as a quality inherent of the system and it is something that exists within systems independently of external hazards, and is generally referred as Social or Inherent Vulnerability (Brooks, 2003). It is determined by factors such as poverty and inequality, marginalisation, food entitlements, access to insurance, and housing quality (Blaikie et al., 1994; Adger and Kelly, 1999; Cross, 2001). According to this prospective the interaction of hazard with social vulnerability produces an outcome, generally measured in terms of physical or economic damage or human mortality and morbidity (Brooks and Adger, 2003) called outcome risk or simply risk. In summary, Biophysical vulnerability is a function of the frequency and severity (or probability of occurrence) of a given type of hazard, while social or social vulnerability is not.

The two definition are both present in the main document produced by IPCC (Intergovernmental Panel on Climate Change), the international reference body in term of climate change (IPCC, 2001; IPCC, 2007). The IPCC Third Assessment Report (TAR) (IPCC, 2001) defines vulnerability as: "The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity." (IPCC, 2001, p. 995) (IPCC Def. 1). And again in 2007 the IPCC definition characterizes vulnerability (to climate change) as a function of a system's exposure and sensitivity to climatic stimuli and its capacity to adapt to their (adverse) effects (IPCC 2007), which corresponds to Biophysical (or end-point) vulnerability, but it does not provide a clear definition of these attributes or the relationship between them. However, the above definition may be compared with that given in Chapter 18 of the TAR, cited from Smit et al. (1999), in which vulnerability is described as the "degree to which a system is susceptible to injury, damage, or harm (one part - the problematic or detrimental part - of sensitivity)" (IPCC Def. 2). The two IPCC definitions above are very different, and are not consistent. IPCC Def. 1 views the vulnerability of a system as a function of its sensitivity, while Definition 2 views vulnerability as a subset of sensitivity. Vulnerability in IPCC Def. 2 is therefore a subset of one of the determinants of vulnerability as defined in IPCC Def. 1, making the two definitions contradictory, provided they are assumed to be describing the same type of vulnerability. This contradiction further illustrates the principal disagreement over the definition of vulnerability within the climate change research community. Anyway, If we view Def. 1 as a definition of Biophysical vulnerability (sensus Brooks, 2003) and Def. 2 as a definition of social vulnerability (sensu Adger, 1999), the conflict is resolved. Finally, we are going to adopting the framework presented by IPCC but throughout some explanation and clarification (Brooks, 2003; Sarewitz et al., 2003).

In our research, the outcome risk is defined as a function of a system's exposure and sensitivity to a natural stimuli and its capacity to adapt to their (adverse) effects (IPCC 2007), which corresponds to Biophysical (or end-point) vulnerability (Brooks, 2003).

The sensitivity of a system is a state characteristic described as the degree to which a system is exposed to injury, damage, or harm (one part - the problematic or detrimental part - of sensitivity) (Smit et al., 1999). An earthquake on the planet Mars is an hazard but the human kind is not sensitive to this hazard as no man living on Mars and no human infrastructure are there present.

The adaptive capacity (e.g. IPCC, 2001; Burton et al., 2002; Adger et al., 2002) may be described as the ability or capacity of a system to modify or change its characteristics or behaviour so as to cope better with existing or anticipated external stresses. Given constant levels of hazard over time, adaptation will allow a system to reduce the risk associated with these hazards by reducing its social vulnerability. Faced with increased hazard, a system may maintain current levels of risk through such adaptation. Together sensitivity and adaptive capacity are defining the inherent vulnerability or social vulnerability (Brooks, 2003).

The separation of vulnerability into inherent vulnerability and biophysical vulnerability or outcome risk enables us to appreciate the compatibility of the risk-based and vulnerability-based approaches (Brooks, 2003). The concept of biophysical vulnerability addresses the same issues as the concept of outcome risk (Sarewitz et al., 2003). Both outcome risk and biophysical vulnerability are functions of hazard and social vulnerability. The essential equivalence of [outcome] risk and biophysical vulnerability as described above is further illustrated by a report from the International Strategy for Disaster Reduction which separates “risk factors” into two components: “hazard (determines geographical location, intensity and probability)” and the ratio “vulnerability / capacities (determines susceptibilities and capacities)” (United Nations, 2002, p.66).

Within this framework, the risk posed to a human system by a particular type of hazard will be a function of the severity and probability of occurrence of the hazard (exposure) and the way in which its consequences are likely to be mediated by the inherent vulnerability. While many factors will determine a system’s capacity to adapt to a variety of existing or anticipated hazards, other aspects will be hazard-specific.

According to the above definition we characterize the model adopted in this study: the risk (R) is defined as a function of exposure to the hazard (H) and inherent vulnerability (V) of human systems to such hazards. In turn, the inherent vulnerability can be assessed as the two main component: Adaptive Capacity (AC) and Sensitivity (S).

The former represent the general ability of a system (institutions, village, individuals, etc...) to adjust itself to any change and environmental stress and to moderate potential damages, to take advantage of opportunities and to cope with the consequences.

Sensitivity is the degree to which a system is potential affected by any environmental stress (generally measured as density of element at risk).

$$R = H * V$$

With the vulnerability (V) determined by the two component:

$$V = S / AC$$

Consequently a risk map is based on an aggregated hazard map and an integrated vulnerability map, and it enables us to see whether the level of risk is related to a region’s hazard potential, its vulnerability or both.

Defined the general conceptual model we can pass to give a definition to the other component of the adopted model.

The hazard is defined how the probability of occurrence of a potential threat to human and their welfare (Kelly and Adger, 2000).

Blaikie et al. (1994) define adaptive capacity in terms of human dimension alone as “the capacity to anticipate, cope with, resist, and recover from the impact of a natural hazard”. Furthermore, Smit and Pilisofa (2003) acknowledges sensitivity or element at risk and adaptive capacity or resilience as the two main components of vulnerability: Vulnerability =

Sensitivity / Adaptive Capacity. The interaction of environmental and social forces determines sensitivities, and various social, cultural, political and economic forces shape adaptive capacity.

Adaptive capacity is context-specific and varies from country to country, from community to community, among social groups and individuals, and over time. Furthermore, the cumulative effects of increased frequency of events near the limit of the coping range may decrease the threshold beyond which the system cannot cope/adapt/recover (Jones, 2001; Dessai et al., 2003).

Adaptive capacity is similar to or closely related to a host of other commonly used concepts, including adaptability, coping ability, management capacity, stability, robustness, flexibility, and resilience (Smithers and Smit, 1997; Adger and Kelly, 1999; Smit et al., 1999; Jones, 2001; Fraser et al., 2003; Tompkins and Adger, 2004; Brooks, 2003; Füssel and Klein, 2006). The forces that influence the ability of the system to adapt are the drivers or determinants of adaptive capacity (Adger, 2003; Turton, 1999; Walker et al., 2002; Wilbanks and Kates, 1999; Blaikie et al., 1994; Kasperson and Kasperson, 2001).

Adaptations are manifestations of adaptive capacity, and they represent ways of reducing vulnerability. Therefore, adaptation, whether analyzed for purposes of assessment or practice, is intimately associated with the concepts of vulnerability. It is in ecological systems that the resilience concepts have been most developed (Berkes et al., 2003; Holling, 2001; Gunderson and Holling, 2002). Although the definition of adaptation in the natural sciences is disputed, it broadly refers to the development of genetic or behavioural characteristics which enable organisms or systems to cope with environmental changes in order to survive and reproduce (Futuyama, 1979; Winterhalder, 1980; Kitano, 2002). Consideration of adaptation within natural sciences encompasses scales from the organism or individual to the population of a single species or an entire ecosystem (Krimbas, 2004). In the context of climate change, Pielke (1998) and later Smit et al. (2000), described adaptations as the adjustments in individual groups, institutional behaviour or generally in ecological-socio-economic system in order to reduce human group's vulnerability to actual climate or expected stimuli.

At the local level the ability to undertake adaptations can be influenced by such factors as managerial ability, access to financial, technological and information resources, infrastructure, the institutional environment within which adaptations occur, political influence, kinship networks, etc. (Watts and Bohle, 1993; Adger, 1999; Handmer et al., 1999; Kelly and Adger, 2000; Toth, 1999; Smit and Pilifosova, 2001; Wisner et al., 2004; Adger et al, 2001; Blaikie and Brookfield, 1987).

Therefore, adaptive capacity and vulnerability explain why, with a given level of natural hazard, people are more or less at risk. Vulnerability refers to the different variables that make people less able to absorb the impact and recover from a hazard event. These may be economic (lack of reserves), social (weak social organisation), technical (poorly constructed housing) or environmental (fragility of ecosystems). This operative definition of vulnerability implies the use of indicators across the range of several "themes": institutions, infrastructure, environment, livelihoods and social factors.

1.3. Review of study on vulnerability and adaptive capacity

There are a growing number of studies dealing with adaptation and vulnerability practices. These studies cover several dimensions: spatial scale (local, regional, national); sector (water resources, agriculture, tourism); type of action (physical, technological, investment, market); actor (national or local government, international donors, NGOs, local communities and households); climatic zone (dryland, floodplains, mountains); baseline development level of the systems in which they are implemented (least-developed countries, middle income countries, and developed countries); or some combination of these and other categories (Adger et al. 2007). This section presents experiences in assessing adaptive capacity and vulnerability of households and communities globally.

Wall and Marzall (2006) presented an example of assessing community capacity in Canadian rural community. The authors used general capacity variables and indicators to focus on impacts of the climate change, and the capacity to adapt to climatic change. A basic framework and profiling tool for describing the resources underlying community adaptive capacity were presented. A set of indicators reflecting social, human, institutional, natural and economic resources is provided and related them to the climate change adaptation at the community level. It is hoped that the ideas and example found in this study will encourage researchers to enhance and improve on the methods and results for work on community capacity.

Swanson et al. (2007) developed a method to investigate characteristics associated with successful adaptive capacity to historic climatic change differs in vulnerability and resilience in the Canadian Prairie. The study developed a geographic information system (GIS) based indicator of the adaptive capacity of agriculturally based communities. The study used 20 indicators representative of adaptive capacity derived for census divisions across the prairies from Statistics Canada sources. The indicators were organized into six determinants: economic resources, technology, infrastructure, information; skills and management, institutions and networks, and equity. The spatial analysis of the adaptive capacity index and its determinants for the 53 census divisions gave a view of the ability of farmers and communities to potentially deal with climate shocks due to the climate change.

Ivey et al. (2004) developed a model of capacity building for communities to cope with water shortages in Ontario, Canada. In the study, concepts relating to the notion of climate adaptation and capacity building were used to elucidate determinants of community-level capacity for water management. These concepts and criteria were used to interpret derived insights relating to local management of water shortages. General determinants of water-related community capacity relate to political and institutional arrangements, the characteristics of pertinent agencies, groups, or individuals involved; and the adequacy of financial, human, information, and technical resources. The case analysis illustrated how general factors play out in local experience; including collaboration between water managers, clarification of agency roles and responsibilities, integration of water management and land use planning, recognition and participation of both urban and rural stakeholders, whose sensitivities to water shortages are spatially and temporally variable.

Connor et al. (2008) evaluated irrigated agriculture sector response and resultant economic impacts of the climate change for a part of a Basin in Australia. A water balance model was used to predict reduced basin inflows for mild, moderate and severe climate change scenarios involving ten, twenty, forty Celsius warming, and predict 13%, 38% and 63%

reduced inflows. Impacts on irrigated agricultural production and profitability were estimated. The model accounted for a range of adaptive responses including deficit irrigation, temporarily fallowing some areas, permanently reducing irrigated area, and changing the mix of crops. The results suggested that relatively low cost adaptation strategies were available for moderate reduction in water availability, thus costs of such reduction were likely to be small. In more severe climate change scenarios greater costs were estimated, adaptations predicted include a reduction in total area irrigated, investments in efficient irrigation, and a shift away from perennial to annual crops as the latter can be managed more profitably when water allocations in some years were very low.

Carraro and Sgobbi (2008) evaluated the economic value of the impacts of the climate change for different economic sectors and regions in Italy. Impacts in any sector and any region were aggregated to provide a macroeconomic estimate of variations in GDP induced by the climate change in the next decades. Autonomous adaptation induced by changes in relative prices and in stocks of natural and economic resources is fully taken into account. The model also considers international trade effects. Results show that aggregate GDP losses induced by the climate change are likely to be small in Italy. However, some economic sectors (e.g. tourism) and the alpine regions will suffer significant economic damages.

Finger and Schmid (2007) developed a model that integrated biophysical simulations in an economic model to analyze the impact of the climate change on Swiss crop production. The study was devoted to the impact of the climate change on crop yield variability. It analyzed corn and winter wheat production on the Swiss Plateau with respect to the climate change scenarios that cover the period of 2030-2050. Adaptation options such as changes in seeding dates, changes in production intensity and the adoption of irrigation farming were considered in the model. Different climate change scenarios, output prices and farmers' risk aversion were applied to show the sensitivity of adaptation strategies and crop yields on these factors. Results showed that adaptation actions, yields and yield variation highly depended on both climate change and output prices. The result showed that simple adaptation measures were sufficient to take advantage of the climate change in Swiss crop farming.

Lehtonen and Kuzala (2007) presented the possible scale of changes in agricultural production and use of farmland in Finland under the climate change scenario. Authors used mean-variance analysis and a sector level, regionally disaggregated, optimization based economic model to evaluate the likely impacts increasing mean and variance of crop yields on agricultural production and land use in Finland. The study finds that farm income was relatively little affected by higher crop yields.

Valdivia et al. (2003) showed that negative impacts of the climate change reduced with mitigation strategies in developing countries. It is said that developing countries in the tropical areas would be worse off than developed countries under different scenarios of the global climate change, due to warmer climates, increased droughts and floods. The study used Bolivia to be an example: a country that experienced climate variability, political change and structural adjustment in the nineties. These forces had an effect on rural livelihood strategies. Canonical correlations identified the elements of strategies that impact on both income and diversity of the household portfolio. The ability of rural people to access resources, accumulate assets, and engage in certain activities allowed some to adapt to variability in the short run, providing insights into characteristics or traits of technologies, markets, and policies that may contribute to long term adaptation.

Alberini et al. (2005) used conjoint choice questions to ask public health and climate change experts about adaptive capacity to certain effects of the climate change on human health. A vector of attributes including per capita income, inequality in the distribution of income, measures of the health status of the population, the health care system, and access to information was drawn in the study. Probity models indicated that per capita income, inequality in the distribution of income, universal health care coverage, and high access to information as important determinants of adaptive capacity. The estimated coefficients and country socio-demographics were used to construct an index of adaptive capacity for several countries. The study concluded that conjoint choice questions provide a promising approach to eliciting expert judgments in the climate change arena.

Artikov et al. (2005) used a meta-economics approach to measure the influence of weather information and forecasts to farmer's adaptive capacity to the climate change. This showed that farmers were not only as rational producers, but also far more emotional than usually considered. Results of the study was expected to help assessing the validity and strengths of the various behavioral sciences, including traditional economic approaches found in the scientific literature for better understanding the general influence of weather forecast and information on decision-making. The meta-economics model showed that farmers were dual and jointly-interested individuals who were influenced by the social context.

Jianping (2008) developed an integrated framework used to design adaptation strategies in Ningxia, China. Stakeholders were involved in the climate change impact prediction. Adaptation measures that Ningxia implemented were also discussed. These include restoration of farmland to forest and pasture and Pasture and Closing Mountain, utilization of climate resources (wind, solar), weather modification, adjustment of crop production structure, adoption of water-saving irrigation, pollution control and release reduction, using news media such as Ningxia Daily propagandize the climate change and its impact for publicity.

Stakeholders in the Mag-Asawang Tubig Watershed of the province of Oriental Mindoro in the Philippines have developed a Co-Benefits Framework for Climate Change Adaptation-Disaster Risk Management establish Telemetric Rain Gauges, and mainstream local climate change adaptation into development plan and strategies. It indicates that different stakeholders involved in the project dovetail with each other in the identification of co-benefits strategies. Enhancing the present resilience of the watershed not only builds capacity for coping with disasters and adapting to the climate change, but also contributes toward overall sustainable development in the area. The study provides a number of recommendations on how to improve adaptive capacity; including enhancing local capability to predict and monitor the climate change impacts, increasing the participation of stakeholders in adaptation efforts, increasing communication between different stakeholders, and mainstreaming the climate change adaptation and mitigation into development strategies and plans (cited in EEPSEA's proceeding of the climate change conference, 2008).

Review of the literature shows that most of previous studies in the field are conducted in developed countries. There was limited research involved enhancing adaptive capacity in developing countries in general and South East Asia region in particular. Among other reasons, this may be due to the lack of expertise, resources to undertake rigorous studies.

1.4. Methodology

The adopted methodology could be represented through a workflow of six steps:

i. Define model to calculate risk;
ii. Determine and define the method to calculate the terms of such model: hazard, vulnerability, sensitivity and adaptive capacity;
iii. Develop indicator for each of the model's terms and component;
iv. Assign weights to the different hazards and component of adaptive capacity;
v. Collect data and analyse it to obtain a normalized value of each terms, for every commune of the study area;
vi. Normalization and homogenization of the data and prepare the layout (maps).

1.4.1. The first step

The rationale behind the adopted model,

$$\mathbf{R = H * S / AC;}$$
$$\mathbf{S / AC = V,}$$

has been illustrated in the first session of the present report. Finally, the overall risk multi hazard Rtot can defined as summation of each single hazard specific risk:

$$R_{tot} = \sum R_i = R_l + R_{ff} + R_d + R_{fl} + R_{wf} + R_{fr} + R_{gl}$$

where:

R_l = outcome risk form landslides;

R_{ff} = outcome risk form flash flood;

R_d = outcome risk form drought;

R_{fl} = outcome risk from flooding;

R_{wf} = outcome risk form wild fire;

R_{fr} = outcome risk frosting;

$R_{gl,}$ = outcome risk form lao wind.

However, the Lao wind risk level was not computed due to wind-related data missing and therefore, the impossibility to modeling the impacts of such wind, in the studied area.

1.4.2. The second step

The second step of our study consisted in organizing and moderating focus group meeting in the three provinces studied. One member of each district's Committee for Flood and Storm Control (CFSC) was invited to join together some relevant member of provincial authorities as expert staff from DARD, DONRE and statistical office. Due to bureaucracy hindrances slowing down the project, such meeting were conducted only in two provinces: Lao Cai and Yen Bai. In this way was achieved the participatory component of our analysis. The meeting developed two phase. During the first one the local experts discussed and defined the natural hazard that affecting the studied provinces. Seven type of hazards were defined by the participant to the focus group meeting, and are listed below:

- Flooding;
- Flash flood;
- Landslide;
- Wildfire;
- Drought;
- Lao Wind;
- Frost.

During the second phase were presented the adopted framework to calculate adaptive capacity (Smit et al. 2001). Within this framework the discussion was stimulated between the participants to develop a list of factors that influencing vulnerability and adaptive capacity to natural hazards of local communities. Assisted by national and international experts, the meeting's participants defined how assess and measure such factors transforming them into indicators of vulnerability or adaptive capacity. Finally, the participants determined the source and the feasibility of the collection of data for each indicator, involving statistical office and committee for flood and storm control at district level, and DONRE and DARD at provincial level. For example, local stakeholders highlighted the importance of education level of local community as factor enhancing adaptive capacity. Then was discussed how measure practically the "education level", for instance using the indicator "percent of student frequenting high education level". Finally, was identified the source of this information in the statistical yearbook of the districts, where this information is reported disaggregated by commune.

After the focus group meeting the research team spent some more day in the each province to visiting provincial DARD, DONRE, statistical office and some district in order to evaluate the availability and the quality of data.

1.4.3. The third step

Hazard and vulnerability, or adaptive capacity, are assumed to be measurable based on attributes or index selected a priori. Our analysis was aimed to determine the hazard level, the sensitivity and the adaptive capacity, using indicators characterized as "quantitative measures intended to represent a characteristic or a parameter of a system of interest" (Cutter et al., 2008). The measurement and the combination of these attributes for every commune of the studied area, will permit to assign a score of hazard and vulnerability to each commune.

The expected application is that adaptation efforts should be directed to those areas with the greatest hazard level or least adaptive capacity or higher vulnerability. Thus, surrogate measures of hazard and elements of adaptive capacity and vulnerability for each system are estimated and then aggregated to generate an overall risk ''score'' (or level or rating) for each system (Adger, 2006).

Mainly two different approaches could be used to develop indices. Theory-driven (also known as deductive) approaches are based on a conceptual framework for identifying relevant indicators and determining their relationships whereas data-driven (also known as inductive) approaches select outcome risk indicators based on their statistical relationship with observed outcomes (e.g., mortality due to natural hazards) (Eriksen and Kelly, 2007). Data-driven approaches have only been applied in the development of outcome risk indices for specific climate-sensitive systems because there is no well-defined outcome that could be used for the development of aggregated outcome risk indices. Moreover, such approach is limited to a complete and consistent data collection on the output risk (as effects, loss, etc...), that are not available in the studied area. Finally, an important limitation of all data-driven indices is that they are being developed and tested in the context of coping with short-term climate variability and extremes rather than adaptation to long-term climate change.

Clarity over its primary purpose is crucial to guide the development of any outcome risk index, or set of indicators. Given the diversity of decision contexts that can be informed by climate change risk assessments and of normative preferences, the design of outcome risk indices is as much a political as a scientific task. Therefore, given the prevalence to the deductive method, for the reason above mentioned, and given the importance of political choice in the selection of outcome risk indices, we adopt the deductive method to develop our indices and indicator, involving experts from the local authorities appointed to "manage the risk", to list the indicators.

The indicator uses to assess the sensibility, adaptive capacity and vulnerability are illustrated in the sessions 3.1, 3.2 and 3.3, respectively. For every one of the seven hazards studied was conducted a literary review to find out the most suitable expression to determine the hazard theoretical level. The result was the definition of seven equations (incorporating several indicators each) that are presented in the session 3.4 Hazard.

Given the context of mountainous areas, and the availability of data in Vietnam, to measure adaptive capacity level, we adopt in this study the determinants framework proposed by Smit et al. (2001) adjusting it to Vietnamese system, for identifying indicators. Starting from this framework the indicators will be identified in collaboration with the local stakeholders to make the best use of data that already existed for all communes in the studied provinces. The five determinants used in this study are:

- Infrastructure vulnerability determinant
- Institutional vulnerability determinant
- Physic vulnerability determinant
- Socio-economic vulnerability determinant
- Human resource vulnerability determinant

For each of the five determinants a list of factors was developed through a process of consultation with relevant stakeholders in the study areas and according to their opinion the factors was transformed in indicators to fill after data collection.

1.4.4. The fourth step

The issue of weightings is highly controversial due largely to the subjectivity inherent in assigning weightings. While the application of weights facilitates an indication of importance of the different variables, it also leaves the results open to manipulation. However, the calculation of an index through the combination of any set of data implies in any case a system of weighting. Putting weights into the formula makes this explicit, and thus more transparent. To ensure that this is the case, the issue of weighting must be explained to users and stakeholders. This is particularly true since weightings modify the relative importance of specific components, and the determination of the importance of any part of an index is a political decision. For the provision of baseline values of climate risk index that take into account the local context and situation, weighting for each indicator, parameter and dimension should be used. It is important to note that also if comparisons are to be made between scores for different locations or situations, the weightings used must be the same in all cases. Therefore, in this climate risk mapping the three different weight sets were developed and applied to all communes within one province.

Weights are effectively multiplicative factors, which are applied to each dimension. When totalled, weights must equal 100 (%). A weight of 30% means that the specific domain score for that particular component is multiplied by 0.3.

Five approaches to allocation of weights are discussed below:

Entirely arbitrary: When weights are chosen without reference to theory or empirical evidence, or even when equal weights are selected, this is classed as 'arbitrary';

Determined by consensus: In this case, policy makers and stakeholders could simply be asked for their views and the choices obtained by consensus;

Determined by policy relevance: Components can be weighted in accordance with public expenditure on particular areas of policy;

Empirically driven: There are two sorts of approaches that might be applicable here. First, analysis of an existing survey might generate weights. Here one might construct a proxy for the issue being examined, and multivariate predictive modelling can be used to derive weights. Second, factor analysis to extract a latent 'factor' representing the issue can be used, assuming that the analysis permitted a single factor solution;

Driven by theoretical considerations: In the theoretical approach, account is taken of the available research evidence, which informs the theoretical model of what is being examined, and weights are assigned according to this. (e.g., if deriving an index of susceptibility to Malaria, the theory suggests that the presence of specific mosquito types is essential to the transmission of Malaria. This would imply that this would have the greatest weight, while other issues, such as presence of standing water, would be less important, and so would have less weight).

Eakin and Bojorquez-Tapia (2008) note that equal weighting makes an implicit judgment about the degree of influence of each indicator and propose a complex fuzzy logic-based weighting method as a more objective approach. Vincent (2004, 2007) and Sullivan et al. (2002) suggest expert opinion and stakeholder discussion, respectively, to determine weighting schemes.

Climate change vulnerability assessment requires interdisciplinary approaches and studies. Impacts caused by extreme climate events in term of affected people, destroyed environment, and economic losses emphasize the need to apply integrated approach to carry out climate risk analysis. Yet, the questions are often raised that which factors are most influential for climate vulnerability in the study area, and also how to quantify them. As mentioned above, many approaches relied only on qualitative weighing factors for underlying factors/indicators. However, "errors" are often made when providing the judgments on the qualitative weights of the comparative factors, this is a consequence of inconsistency in rating the importance among relevant factors. The Analytic Hierarchy Process deals formally with these "errors" by estimating the overall weights using the information contained in the matrix of factors, in which the consistency ratio is estimated to measure how much is the inconsistency in filling the matrix of factors. This climate vulnerability mapping, therefore, applied an approach to define climate risk factors which are determined by researchers and approved by policy makers and stakeholders in three provinces, and then to quantitatively evaluate the weighing factors based on the views and consensus of key stakeholders and policy makers with the support of AHP tool.

1.4.4.1. Analytic Hierarchy Process (AHP) - The method

The AHP was first developed by Thomas L. Saaty in the 1970s and, since that time, has received wide application in a variety of areas. It has been defined differently as follows: a robust and flexible methodology for multi-criteria decision analysis; the art and science of decision making but as an intuitive and relatively easy method for formulating and analyzing decisions; and a tool to permit explicit exhibition of appraisement criteria and also a multi-attribute decision method, which refers to quantitative technique. The AHP has been used in many practical problems in economics, transportation, education, resources allocation, planning, and integrated management. The AHP is widely used because of a number of advantages such as it is a structured decision process and quantitative process which can be documented and replicated; it is applicable to decision situations involving multi-criteria and subjective judgment; it can deal with both qualitative and quantitative data; it can be used to check consistency of preference; and it is suitable for group decision-making.

The purpose of the AHP was to quantify the qualitative preferences among components or subcomponents as well as indicators or categories. The pair-wise comparison of set of objects (either criteria or alternatives) was used to evaluate interactive weights of the components. The scoring of pair-wise judgment is based upon rule of Saaty with a 9-point system from 1 (in case of two activities contributing equally to the objective) to 9 (in case of the evidence favoring one activity, which is extremely preferred over another); the other scores such as point 3 refers to weak importance, point 5 assigned for obvious preference, point 7 for the case of strong significance; and the remaining even numbers, for instance points 2, 4, 6, 8, are used when a compromise is needed between odd numbers.

Table 1: **Saaty Scale for Pair-wise Comparison**

Intensty of importance	Definition	Explanation
1	Equal importance	Two factors contribute equally to the objective.
3	Somewhat more important	Experience and judgement slightlty favour one over the other.
5	Much more important	Experience and judgement strongly favour one over the other.
7	Very much more important	Experience and judgement very strongly favour one over the other. Its importance is demostrated in practise.
9	Absolutely more important	The evidence favouring one over the other is of the highest possible validity
2, 4, 6 and 8	Intermediate values	When compomise is needed

The AHP was undertaken for quantitative evaluation of relative weights of climate vulnerability factors. Fig. 1 depicts the algorithm of AHP used to compute the relative weights to climate risk components for the study area.

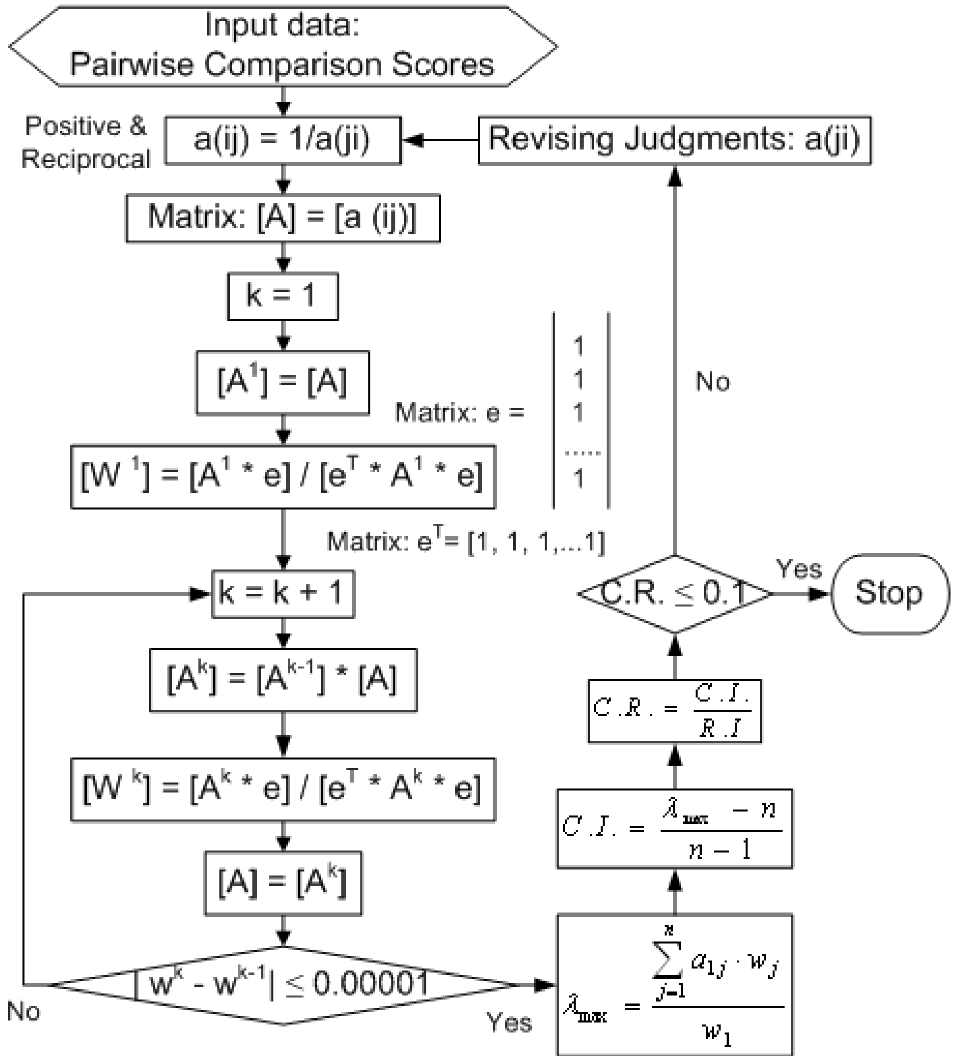


Figure 1: Algorithm of AHP

In Fig. 1, the matrix A = [aij] was established following the rule that is positive and reciprocal. Coefficients of the matrix were formed from scoring of pair-wise comparison of components, subcomponents, indicators, and categories of climate risk through focus group discussion (FGD) of local experts, policy makers and relevant stakeholders at provincial levels in three provinces of Phu Tho, Yen Bai and Lao Cai. The relative weights of components were derived from mathematical processing of the matrix using AHP algorithm (Fig. 1) that the free software for this processing is available online (http://www.isc.senshu-u.ac.jp/~thc0456/EAHP/AHPweb.html).

The weights were computed as the principal right eigenvector (or Perron right vector) of the matrix, which was accomplished by raising the matrix A to growing power k. The increasing power k of matrix A was iterated until the difference of priority weight vector of two last repetitions was less than permitted error of 0.00001. Each iteration, the weights were always normalized so that it summed to 1 for convenience. Ultimately, the maximum Eigen value (□max) of the matrix A was then defined. The preference factors were checked for consistency through the consistency ratio (C.R.), which was the ratio of random inconsistency index (R.I.) and consistency index (C.I.). According to Harker (1989), the C.R. below 0.1 is typically considered acceptable but higher values require revising judgments to reduce the inconsistencies. The C.I. is synthesized from λ_{max} and order of the matrix (n). The R.I. is a function of n in the relationship given by Saaty (1980) as follows:

Table 2: RI value of matrix (n)

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R.I.	0.0	0.0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

1.4.4.2. Development of Hierarchy

The hierarchy of climate risk components is developed to build the matrices for applied AHP (See Fig. 2 for the details of weighting process). Components, subcomponents, indicators and categories are arranged like a tree root with four levels as illustrated in Fig. 2. The ultimate goal is to represent the overall climate risk of a commune. The second level is to present climate risk of different climatic related hazards. For example climate risk related to flood, typhoon and drought are presented at this level. The third level presents two components: vulnerability and pressures of respective hazard. The fourth level presents two components: adaptive capacity, sensibility and factors of a specific hazard of the second level and details indicators of pressure. The fifth level presents the subcomponents of adaptive capacity, and sensibility, and the final level presents the indicators each subcomponent of adaptive capacity and sensibility. Each commune contains characteristics related to climatic risk. Thus, magnitudes of all indicators in each commune are defined and the relative weights are calculated. Consequently, the value of climate risk for each commune is integrated by summation of magnitudes of all indicators with respect to their weights. Mapping of all communes gives comprehensive climate risk map.

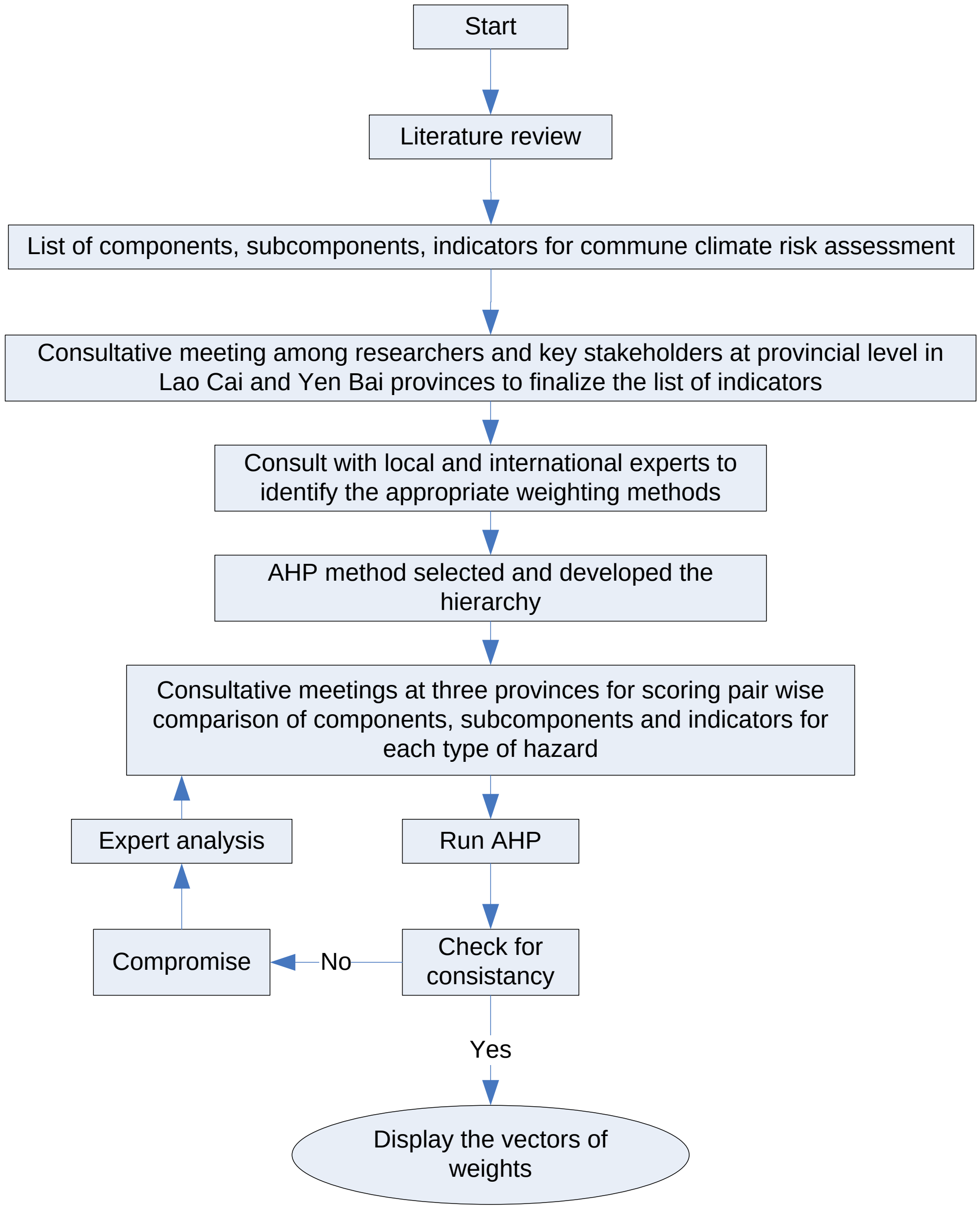


Figure 2: The weighting process

The scoring for the matrices of components, subcomponents, and indicators of risk was implemented through consultative meetings with local experts coming from department of agriculture and rural development at district and provincial levels, and other relevant departments. One consultative meeting was organized for each province. A total of 32 local experts who have experiences and competent in the field of climate risk were invited through three meetings.

1.4.5. The fifth step

During the field trip the consultant team visited the provincial Department of Natural Resources and Environment (DONRE) and district office of Department of Agriculture and Rural Development (DARD) in order to discuss availability of data. In the frame, the consultant team revisited jointly with PMB and provincial coordinators the possibly source of data to fill the indicators proposed. Four main sources was individuated:

- District CFSC office,
- General Statistic Office of Vietnam,
- Provincial DONRE,
- Mid North Hydro-meteorological Service.

The district CFSC office was involved to assess the ability of the institution to face and to cope with natural disaster and to manage the risk. A questionnaire form for collection of data at district and communal CFSC and Statistic Office are prepared and translated in Vietnamese. The form was sent to the district CFSC office trough the provincial coordinators, that later collect it back and digitalize the information in excel file format. The questionnaire form include several questions grouped to define the indicator to compute the institution component for the adaptive capacity.

- Commune leader’s school diploma;
- Level of experience (bad, normal, good, excellent) of commune leader to manage emergencies and risks;
- Level of efficiency (bad, normal, good, excellent) of commune leader to cooperate with district CFSC during a climate emergency;
- Level of efficiency (bad, normal, good, excellent) of commune leader to cooperate with district CFSC to manage and prevent climate risk;
- Consistent level (bad, normal, good, excellent) of CFSC commune staff in the commune;
- Level of experience (bad, normal, good, excellent) of CFSC commune staff to manage emergencies and risks;
- Level of efficiency (bad, normal, good, excellent) of CFSC commune staff to cooperate with district CFSC during a climate emergency;
- Existence of emergencies or risk management plan at commune level;
- Effectiveness of emergencies or risk management plan at commune level;
- Frequency of updating of emergencies or risk management plan at commune level;
- Number of the loudspeaker available in a commune;
- Number of public building potentially employed as disaster shelter;
- Percentage of population involved in emergencies drills;
- Number of event and economic loss due to every hazard studied.

The General Statistic Office (GSO) of Vietnam furnish the dataset of population and house census 2009 and the map of administrative boundary for the three provinces.

The provincial DONRE and the correspondent Ministry of Natural Resources and Environment supply the project activities with some digital cartography in shapefile or map info format (GIS) or Microstation format (CAD). The supplied cartography is listed below:

- Land use 1:50,000
- Forestry map (2009)
- Vietnam map VN 2008

Finally, the Mid North Hydro Meteorological Service make available their digitalize data, that are limited to the last five years. Therefore, the consultants decide to assess to online available climatic data through internet. Two main dataset was downloaded:

- Worldclima, from 1950 to 2000 with resolution of 30 second of arc (about 1 Km). The monthly average precipitation, mean temperature, maximum temperature and minimum temperature were mined from this dataset (Hijmans et al., 2005).
- CRU CL 2.0, from 1961 to 1990 with resolution of 10 minute of arc (about 20 Km). The monthly average of relative humidity and the average monthly frequency of frost were mined from this dataset (New et al., 2002).
- CRU TS 3.1, from 1901 to 2009 with resolution of 30 minute of arc (about 60 km). The monthly precipitation, mean, maximum and minimum temperature were mined from this dataset (Mitchell and Jones, 2005).

The implementation with the Mid North Hydro Meteorological Service’s data was not possible as they hold data in not digital format. The digitalization of such data is timing expensive and request to employ and pay several technical staff to conduct this efforts. Therefore, the consultant decided to limit the study to the available online data. Furthermore, we downloaded the ASTER DEM with resolution of 30 meter from NASA to develop the morphological indicators, as the topographic map available at provincial or national level did not report the database linked with the contour line (because developed in a CAD environment as Microstation), therefore is not possible build up a DEM from such dataset.

1.4.6. The sixth step

All the collected data was georeferenced at Coordinate Reference System UTM 48 zone North, datum WGS84.

Than the data were processed and were extracted and analyzed to define the indicator.

Before data are to be combined, they first need to be normalized, and then weighting needs to be considered. To overcome problems of incommensurability, data must be normalized so that each component (domain) has a common distribution and is not scale dependent. The normalization process also facilitates easy identification of the best and worst areas.

Normalizing component score means putting them on the same scale. In this study, scores for each indicator will be calculated by the formula:

$$\mathbf{1 + 9 * (X_i - X_{min}) / (X_{max} - X_{min})}$$

Where X_i, X_{max} and X_{min} are the original values for location i, for the highest value commune, and for the lowest value commune respectively. The score for any one indicator then lies between 1 and 10.

For the indicator that have to assume a negative impact on the index, will be used an inverse normalization:

$$\mathbf{10 - 9 *(X_i - X_{min}) / (X_{max} - X_{min})}$$

After that, for the spatial data, we calculated the average value for each communes we compute a commune level value’s.

2. Analytical Hierachical Process (AHP) results

2.1 Results of indicator weighting

During the consultative meeting local experts were consulted for the pair-wise comparisons of the risks amongst the hazards identified in their province.

Table 3: Results of pair-wise comparison for climatic risk for each hazard in Lao Cai

	Flash flood	Landslide	Flooding	Drought	Wildfire	Lao Wind	Frosting
Flash flood	1	3	3	5	3	5	5
Landslide		1	1	5	3	5	5
Flooding			1	5	5	5	5
Drought				1	1 / 3	1 / 3	1 / 5
Wildfire					1	1 / 3	3
Lao Wind						1	3
Frosting							1

Table 4: Weight of specific hazard risk in Lao Cai

Hazard	Weights
Flash flood	0.34
Landslide	0.20
Flooding	0.22
Drought	0.03
Wildfire	0.07
Lao Wind	0.09
Frosting	0.05

Table 5: Results of pair-wise comparison for adaptive capacity components in Lao Cai

	Institutional	Infrastructure	Natural	Economic	Social
Institutional	1	3	3	3	3
Infrastructure		1	3	1	1
Natural			1	1 / 3	1 / 3
Economic				1	1
social					1

Table 6: Weight of adaptive capacity components

Component	Weights
Institutional	0.42
Infrastructure	0.17
Natural	0.07
Economic	0.17
social	0.17

Table 7: Results of weighting for specific hazard risk in Phu Tho, Yen Bai and Lao Cai

Hazards	Lao Cai	Yen Bai	Phu Tho
Flash flood	0.34	0.15	0.24
Landslide	0.20	0.10	0.03
Flooding	0.22	0.44	0.21
Drought	0.03	0.14	0.31
Wildfire	0.07	0.09	0.05
Lao Wind	0.09	0.03	0.10
Frosting	0.05	0.06	0.06

Table 8: Sets of weights for adaptive capacity in Phu Tho, Yen Bai and Lao Cai

Components	Lao Cai	Yen Bai	Phu Tho
Institutional	0.42	0.19	0.46
Infrastructure	0.17	0.11	0.22
Natural	0.07	0.13	0.08
Economic	0.17	0.18	0.06
Social	0.17	0.38	0.19

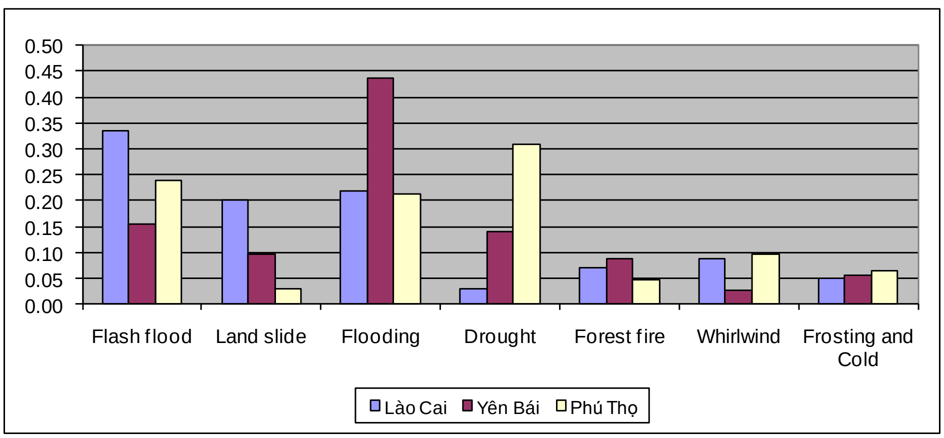


Figure 6: Results of weighting for specific hazard risk in Phu Tho, Yen Bai and Lao Cai

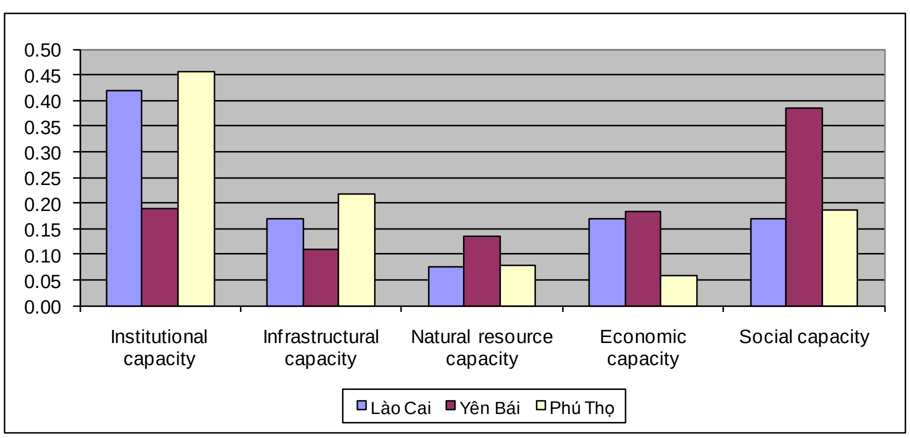
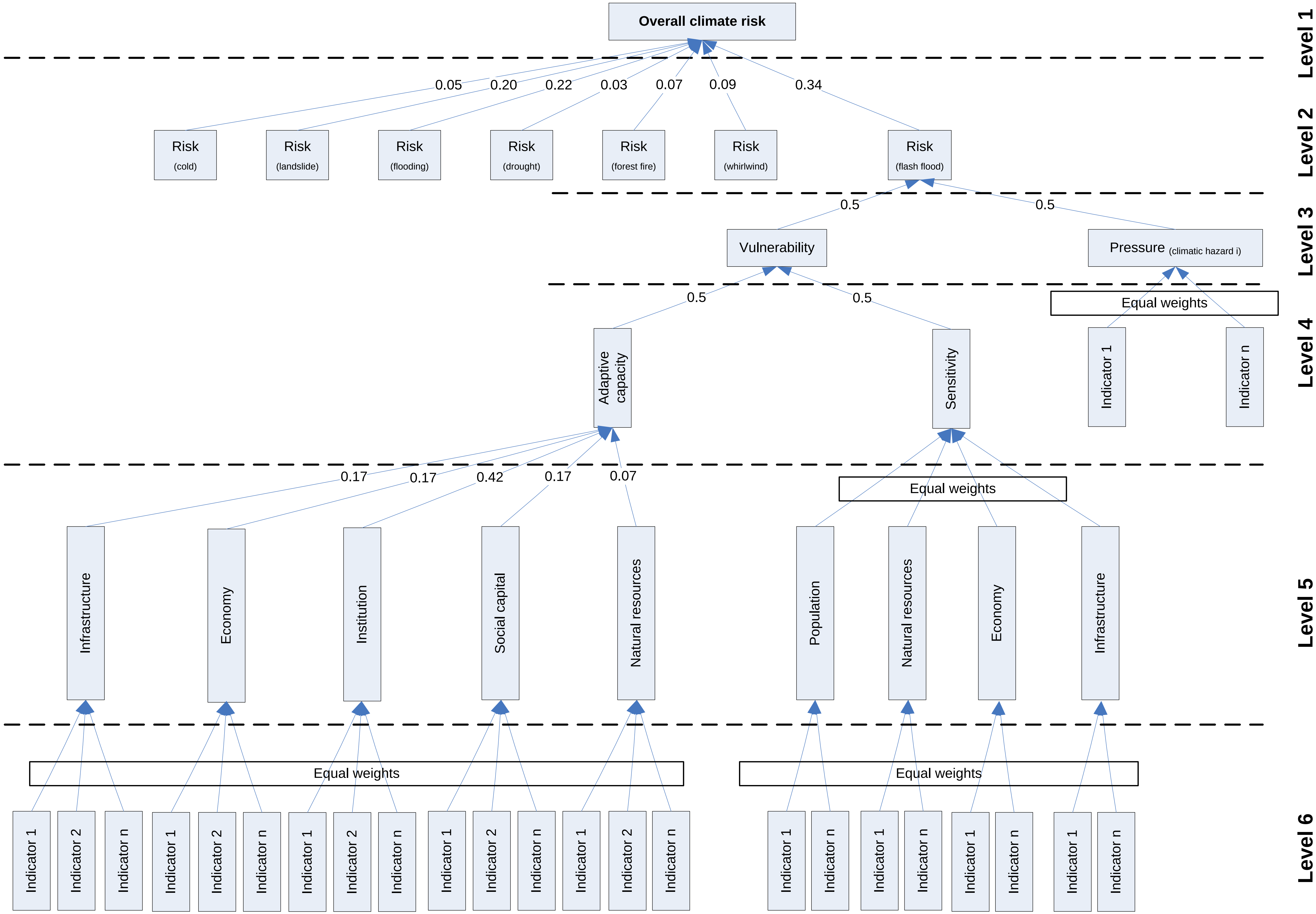
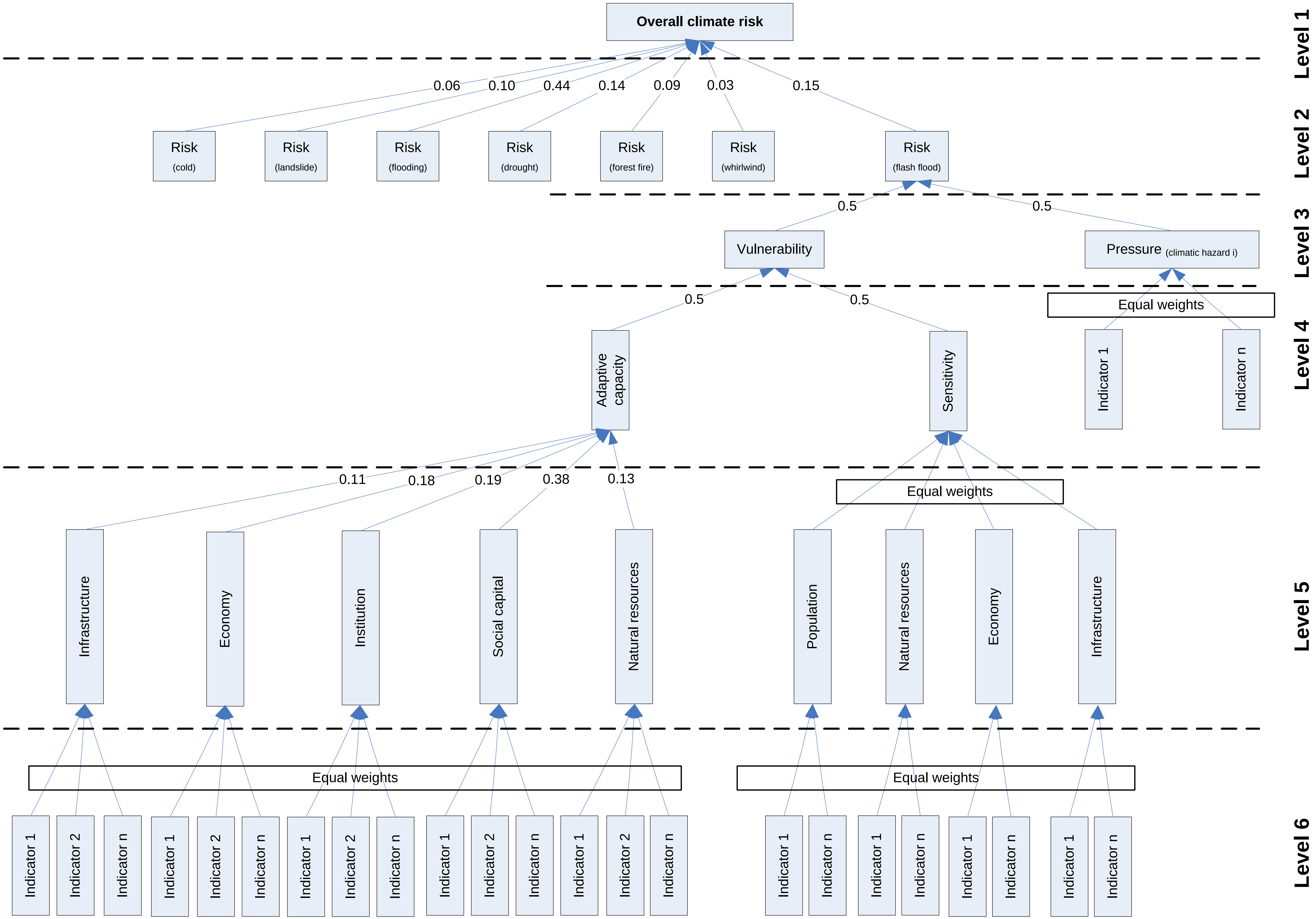


Figure 7: Weights for adaptive capacity in Phu Tho, Yen Bai and Lao Cai

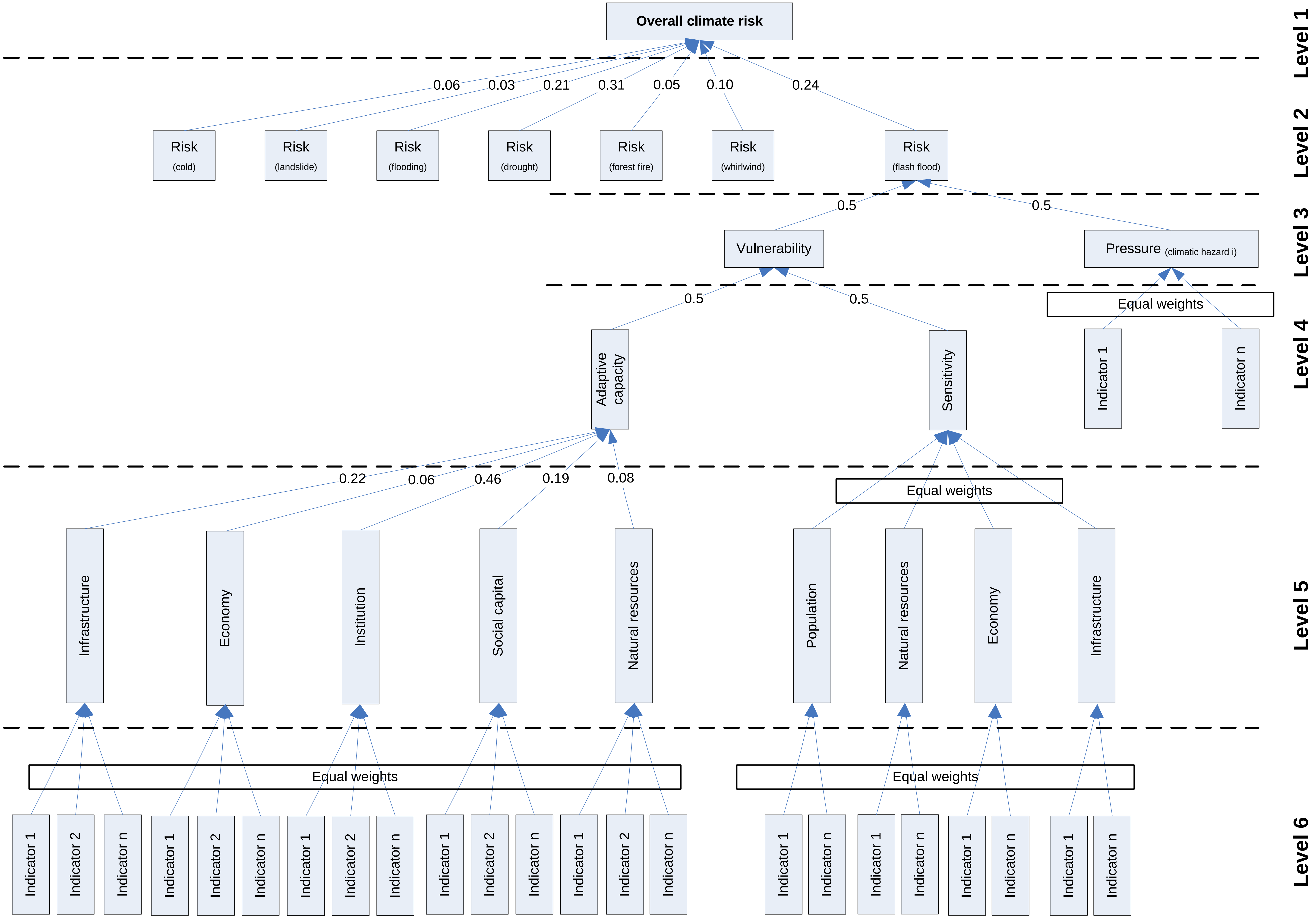
Weighting Set For Lao Cai Province



Weighting set for Yen Bai Province



Weighting Set For Phu Tho Province



3. Indicators

According to the mathematical function above presented (formula n° 1, § 1.2) for calculate the overall risk index we should before calculate the vulnerability and hazard level index for the communes of the three Northern provinces of Vietnam here studied. The following set of indicators to define such indexes, are the product of the focus group meeting carried out in two of the three provinces.

Frequency and intensity of natural hazard in the last five years and the institutional capacities to manage risk (i.e. institutional adaptive capacity) due to natural hazard were assessed throughout a questionnaire deployed in each communes of the studied area last year. The data collection was completed by the end of 2010 and during the spring the data were reviewed and some additional control was carried out. Unfortunately several communal authorities of the target provinces don't have archived data systematically about the impact and the frequency of the different natural hazard impacting the communes. Therefore, a full comparison between the different commune was not possible using such data.

Furthermore, the spatial information (maps) of impact of hazard in the three provinces is not uniformly achieved. Only the province of Phu Tho has a consistent digital map on flash floods hazard for the whole province.

The National Hydro-Meteorological Service and his regional branch (Mid-North Hydro-Meteorological Service) were contacted for the availability of climatic data. In the area there are 27 meteorological stations. This institution collect meteorological data for more than 30 years (since 1975, even more for some station). However, the data are not yet digitalized. The effort to digitalize the meteorological data is a need of future enhancement of hazard study in the study area. Therefore, the team establish an agreement with the Climatic Research Unit and the Tyndall Centre for Climate Change Research both at East Anglia University aimed to get their climatic database in relation to the study area.

Table 9: climatic dataset

Reference	Space resolution	Time	Variables
New et al., 2002	18 Km	1961-1990	pre, wet, tmp, dtr, rhm, ssh, frs, wnd
Mitchell and Jones, 2005	54 Km	1901-2006	pre, tmp, tmx, tmn, dtr, vap, cld, wet, frs, wnd
Cld	Percentage of cloud cover		
Frs	Frost day frequency (days)		
Pre	Millimeters of precipitations		
Rhm	Percentage of relative humidity		
Tmn	Monthly daily average minimum temperature (Celsius degree)		
Tmp	Daily mean temperature (Celsius degree)		
Tmx	Monthly daily average maximum temperature (Celsius degree)		

The topographic maps available in Vietnam was developed in Microstation format (CAD). Later the graphic features was exported to GIS software format (shapefile). However, such dataset did not present the elevation quote associated to the contour figures. Therefore, we decided to use the ASTER Global Digital Elevation Model (GDEM) to develop the topographic parameter. Such Model were released by NASA and Japan's Ministry of Economy, Trade and industry on June 29, 2009. The GDEM is produced with 30 meter postings. Finally the assessment team purchased the land use map 2010 (from MONRE) and the forest map 2009 (from FIPI) both at scale 1:50,000.

According the following table were computed all the index here used to compute vulnerability. Such index are detailed discussed in the next three sections (3.1, 3.2, 3.3). The section 3.4 will introduce the methodology used to compute the commune hazard level. Finally the section 3.5 illustrate the calculation of hazard risk level.

3.1 Sensitivity

3.1.1 Indicator of sensitivity

The sensitivity is the problematic or detrimental part of vulnerability (Smit et al., 1999), and is described as the "degree to which a system is susceptible to injury, damage, or harm" (IPCC, 2007 Def. 2). The sensitivity of a system is a state characteristic described as the degree to which a system is exposed to injury, damage, or harm. An earthquake on the planet Mars is an hazard but the human kind is not sensitive to this hazard as no man living on Mars and no human asset are there present.

Two main class of element are at risk, human (fatalities) and several type of asset (financial loss). The measure the human sensitivity were used the population density. Giving that the studied area has an economy mainly based on agriculture, were use the density of the agriculture land as proxy of the main economical assets.

To compute the sensitivity of the system to the hazard we adopt two simple indicators to represent the density of element at risk: human population and agriculture land density for each commune. One more indicator could be the percentage of agriculture income on the total income produced in the three provinces. However the data to estimate agriculture income are not updated and even incomplete, preventing the computation of such indicator in the study area. Such gap could be filled in the close future once the data of the next agriculture census will be released by the General Statistic Office of Vietnam.

3.1.1.1 Population Density Index (PDI)

The population density is largely use in the scientific literature as classical indicator of human sensibility to natural disaster (Gaillard et al, 2007). It was the first indicator of vulnerability used in natural hazards assessment (UNEP, 2000).

Data source of population from General Statistic Office of Vietnam 2009 population census and area from administrative layer GSO. The logarithm of the ratio was used to decrease the large differences between rural and urban commune. Alternatively the assessment could be conducted separately for the two different systems (urban and rural). However, requested the establishment of a threshold between rural and urban system that was not possible define according the local stakeholders and the Vietnamese administrative classification.

Unit of measurement: people / square Km

PDI = Ln (people / commune area)

Range from 0.99 to 7.82 people / square Km; no value = - 999

Normalization (from 1 to 10): $PDI_n = 1 + 9 * (PDI – 0.99) / (7.82 – 0.99)$

Table 10: list of index for vulnerability (XXXn means normalized index; XXXin means inverse normalized index; # means spatial average)

PDI	Population Density Index	ln (PEOPLE / AREA)	natural logarithm of human density (people per Km^2)
ALDI	Agriculture Land Density Index	AGRILAND / AREA	agriculture assets density
SENSIT	Sensitivity Index	(PDIn + ALDIn) / 2	sensitivity
LCI	Leader Capacity Index	EDU_LEAD + EXP_LEAD + EMER_LEAD + PREP_LEAD	commune leader adaptive capacity
CCFSCI	CCFS Capacity Index	ADEQ_STAFF + EMER_STAFF + PREP_STAFF	commune CFSC adaptive capacity
RMPI	Risk Management Planning Index	PLAN_EFF * PLAN_UPD	risk plan adaptive capacity
EDPI	Emergency Drills Participation Index	EME_DRILL	participation to emergency drills
AC_INST	Adaptive Capacity, Institutional component	(LCIn + CCFSCIn + RMPIn + EDPIn) / 4	institutional component of adaptive capacity
RDI	Road Density Index	ROAD_LENGH / AREA	roads density
HQI	House Quality Index	(PPH + 2 * PAPH / 3 + PSPH / 3) / 2 + (PCRH + PBWH) / 4	house quality
PBI	Public Building Index	1000 * PB / PEOPLE	public building as shelter per 1000 people
EHI	Electricity House Index	EH	diffusion of house electricity
TWTI	Tape Water and Toilette Index	(PHTW + PHSTI) / 2	diffusion of toilette and tape waters
RSDI	Railway Station Density Index	#	average distance from railway stations
AC_INFR	Adaptive Capacity, Infrastructure component	(RDIn + HQIn + PBIn + EHIn + TWTIn + RSDIn) / 6	infrastructure component of adaptive capacity
URI	Unemployed Rate Index	UR	unemployed rate
PHI	Poverty Housing Index	PWH	proxy for assess poor household distribution
AC_ECON	Adaptive Capacity, Economic component	(URIin + PHIin) / 2	economic component of adaptive capacity
GRI	Gender Rate Index	PW	percentage of women per commune
UPI	Underage Percentage Index	PUP	percentage of people under 18 years old
EPI	Elder Percentage Index	PEP	percentage of people above 60 years old
PEMI	Percentage Ethnic Minority Index	PEM	percentage of people belong to ethnic minority
FSI	Family Size Index	PEOPLE / HHS	average size of family
ARI	Alphabetization Rate Index	PPRW	percentage of people can read and write
ASYI	Average Schooling Years Index	(PSY1 * 1 + PSY2 * 2 + PSY3 * 3 + PSY4 * 4 + PSY5 * 5 + PSY6 * 6 + PSY7 * 7 + PSY8 * 8 + PSY9 * 9 + PSY10 * 10 + PSY11 * 11) / 100	average schooling years
AC_SOCI	Adaptive Capacity, Social component	(GRIin + UPIin + EPIin + PEMIin + FSIin + ARIn + ASYIn) / 7	social component of adaptive capacity
CVI	Climate Variability Index	#	climate variability in the last century
FLI	Flat Land Index	#	percentage of land flat and thus easy to farm
ALAI	Agriculture Land Availability Index	1000 * AGRILAND / PEOPLE	availability of farmed land per 1000 people
PNFLAI	Protected and Natural Forest Land Availability Index	1000 * FORLAND / PEOPLE	availability of protected and natural forest per 1000 people
AC_NATU	Adaptive Capacity, Natural component	(CVIin + FLIn + ALAIn + PNFLAIn) / 4	natural component of adaptive capacity

3.1.1.2 Agriculture Land Density Index (ALDI)

The agriculture land density were used as proxy of agriculture asset, to evaluate the sensitivity to material loss due to natural hazards.

Data source from land use map 2010 produced by MONRE. (exported figures of agriculture activity than was performed a spatial analysis to assign to each polygon of agriculture land the commune GSO code taken from the administrative layer of GSO)

Unit of measurement: hectare / square Km

ALDI = hectare agriculture land (ha) / commune area (square Km)

Range from 0 to 96.06 hectare per square Km

Normalization (from 1 to 10): $ALDI_n = 1 + 9 * ALDI / 96.06$

3.1.2 The sensitivity index (SENSIT)

The sensitivity index was calculated as mathematical average of the two component above illustrated

$SENSIT = (PDI_n + ALDI_n) / 2$

The sensitivity Index range from 1.08 to 9.39, no value = -999

3.2 Adaptive Capacity

The adaptive capacity (e.g. IPCC, 2001; Burton et al., 2002; Adger et al., 2002) may be described as the ability or capacity of a system to modify or change its characteristics or behaviour so as to cope better with existing or anticipated external stresses. Given constant levels of hazard over time, adaptation will allow a system to reduce the risk associated with these hazards by reducing its social vulnerability. Faced with increased hazard, a system may maintain current levels of risk through such adaptation. Together sensitivity and adaptive capacity are defining the inherent vulnerability or social vulnerability (Brooks, 2003).

The adaptive capacity was divided in five group of indicator, namely: Institutional adaptive capacity, Infrastructure adaptive capacity, Economical adaptive capacity, Social adaptive capacity and Natural adaptive capacity.

The table below, highlights the rationale behind such classification (Smit et al., 2001).

Table 11: Adaptive capacity determinants and their rationale (modified from Smit et al, 2001)

Determinant	Rationale
Institution	Well developed, organized and equipped social institutions help to reduce impacts of climate related risks, and increase the resilience of local community.
	Policies and regulations can constrain or enhance adaptive capacity.
Infrastructure	Greater variety of infrastructure can enhance adaptive capacity, since it provides more options to the stakeholders.
	Characteristics and location of infrastructure also affect adaptive capacity.
Natural	Equitable distribution of resources increases adaptive capacity.
	Both availability of, and entitlement to, resources is important.
Economic	Grater economic resources increase adaptive capacity.
	Lack of financial resources limits adaptation options.
Social	Lack of informed, skilled and trained personnel reduces adaptive capacity.
	Greater access to education, technology and information increases likelihood of timely and appropriate adaptation.

Several indicator were used to compute the different component of adaptive capacity. In the following sub section (from 3.2.1 to 3.2.5) they are discussed.

3.2.1 Institutional adaptive capacity component

A strong, experienced and prepared administrative leader and staffs, abundant emergencies equipment and early warning system (i.e. loudspeakers), the ability to plan the management of risk and emergencies and, finally, the preparation of a large part of population to conduct emergencies operation are factors that increase the adaptive capacity of a human society. The institutional component of adaptive capacity was assessed though data collected with a simple questionnaire survey to the district and commune office of Committee for flood and storm control. Such indicators should be able to evaluate the quality and the effectiveness of the office assigned to face disasters and emergency at communal level and evaluate the quantity of emergency structures (emergency team, equipments and map/plans). The indicators on leader and communal staff were been quantified by the judgement of experts from each districts.

3.2.1.1 Leader Capacity Index (LCI)

Data source from questionnaire survey: question 1 (Q1) = leader education level; question 2 (Q2) = leader experience level to cope with emergencies and risk; question 3 (Q3) = leader capacity to cooperate with district CFSC during emergencies; question 4 (Q4) = leader preparedness

Measurement unit scale: Bad =1, Normal = 2, Good = 3, Excellent = 4

LCI = Q1 + Q2 + Q3 + Q4

Range from 6 to 16, no value = -999

Normalization (from 1 to 10): $LCI_n = 1 + 9 * (LCI – 6) / (16 – 6)$

3.2.1.2 CFSC Capacity Index (CFSCCI)

Data source from questionnaire survey: question 5 (Q5) = adequacy of the quantity of commune CFSC staff; question 6 (Q6) = commune CFSC staff capacity to cooperate with district CFSC during emergencies; question 7 (Q7) = commune CFSC staff preparedness

Measurement unit scale: Bad =1, Normal = 2, Good = 3, Excellent = 4

CFSCCI = Q5 + Q6 + Q7

Range from 4 to 12, no value = -999

Normalization (from 1 to 10): $CFSCCI_n = 1 + 9 * (CFSCCI – 4) / (12 – 4)$

3.2.1.3 Risk Management Plan Index (RMPI)

Data source from questionnaire survey: question 8 (Q8) = effectiveness of the emergencies and risk management plan; question 9 (Q9) = update frequency of the emergencies and risk management plan

Measurement unit scale (Q8): Bad =1, Normal = 2, Good = 3, Excellent = 4; No plan = 0

Measurement unit scale (Q9): Every month = 24; every 1-2 months = 16; every 2 months = 12; every 3 months = 10; every 4 months = 8; every 5-6 months = 6; every 7-8 months = 4; every 9-12 months = 2; more than 12 months = 1

RMPI = Q8 * Q9

Range from 0 to 96, no value = -999

Normalization (from 1 to 10): $RMPI_n = 1 + 9 * RMPI / 96$

3.2.1.4 Emergency Drills Participation Index (EDPI)

Data source from questionnaire survey: question 10 (Q10) = which percentage of the commune population on average participate to emergencies drills

Measurement Unit: percentage of people participating to emergencies drills

EDPI = Q10

Range from 0 to 100, no value = - 999

Normalization (from 1 to 10): $EDPI_n = 1 + 9 * EDPI / 100$

3.2.1.5 Institution Adaptive Capacity Index (AC_INST)

The overall institution adaptive capacity index (AC_INST) is measured as the mathematical average of the five indicators listed above.

$AC\_INST = (LCI_n + CFSCCI_n + RMPI_n + EDPI_n)/4$

Range from 1.25 to 8.09, no value = -999

3.2.2 Infrastructure adaptive capacity component

The infrastructure component of adaptive capacity is enhanced from the abundance and good quality of transportation system (road and railway), from the quality (electricity, roof, toilette) and capacity to resist to natural hazards of homes, and, finally, from the possibility to guest in safe shelters a large part of population without excesses overcrowding.

The data on infrastructure adaptive capacity are mainly extrapolated by the land use map 2010 (MONRE) for transportation system and from the GSO population census 2009 for the homes quality. The public shelters were assessed through the questionnaire survey in all communes of the studied area.

3.2.2.1 Road Density Index (RDI)

Data source from land use map 2010 produced by MONRE. (Exported polyline of transportation). An high density of road density facilitate the emergencies operation and increase the economical efficiency of local communities, therefore increasing their adaptive capacity to climate stimuli.

RDI = 16 * A + 8 * B + 4 * C + 2 * D + E,

With A = Km of national road; B = Km of provincial road; C = Km of city street; D = Km of inter-commune road; E = Km of other small road

Measurement unit: Km of road / square Km

Range from 0 to 29.56.

Normalization (from 1 to 10): $RDI_n = 1 + 9 * RDI / 29.56$

3.2.2.2 House Quality Index (HQI)

Data source from General Statistic Office of Vietnam 2009 population census. Permanent house with concrete roof and wall are less vulnerable to natural hazards and protect better the population during emergencies.

HQI = (PPH + 2 * PAPH / 3 + PSPH / 3) / 2 + (PCRH / 4) + (PBWH / 4)

With PPH = percentage of permanent house; PAPH = percentage of almost permanent house; PSPH = percentage of semi permanent house; PCRH = percentage of concrete roof house; PBWH = percentage of brick-stone wall house

Range from 0.94 to 98.46, no value = -999

Normalization (from 1 to 10): $HQI_n = 1 + 9 * (HQI – 0.94) / (98.46 – 0.94)$

3.2.2.3 Public Building Index (PBI)

Data source from General Statistic Office of Vietnam 2009 population census for population census and from questionnaire for number of public building: question 12 (Q11) = number of public building potentially used as shelter during emergencies. Shelters available in case of emergencies enhance the capacity to adapt to natural hazards.

PBI = Q11 * 1000 / population,

Measurement unit = public building per thousand of people

Range from 0 to 99.50, no value = -999

Normalization (from 1 to 10): $PBI_n = 1 + 9 * PBI / 99.50$

3.2.2.4 Electricity House Index (EHI)

The household that cannot access to electricity are generally less able to adapt to natural hazards (Cutter et al., 2003).

Data source from General Statistic Office of Vietnam 2009 population census

Measurement unit: percentage of house with electricity

Range from 0 to 100, no value = -999

Normalization (from 1 to 10): $EHI_n = 1 + 9 * EHI / 100$

3.2.2.5 Tape Water Toilette Index (TWTI)

Households with toilette and tape water are less vulnerable to natural hazard (Cutter et al., 2003), because enhance the adaptive capacity, and furthermore, the habitant of homes with tape water are less prone to disease outbreak after a natural disaster.

Data source from General Statistic Office of Vietnam 2009 population census

TWTI = (PHTW + PHSTI) / 2

With PHTW = percentage of house with tap water; PHSTI = percentage of house with septic tank toilette inside

Range from 0 to 93.18, no value = -999

Normalization (from 1 to 10): $TWTI_n = 1 + 9 * TWTI / 93.18$

3.2.2.6 Railway Station Distance Index (RSDI)

Generally after a natural disaster the train is one of the main vectors to bring food, medicine and helps to local population. Therefore, the distance between a village and the railway station is a good proxy to measure the easily how the people can receive aids.

Data source from land use map 2010 produced by MONRE. (Exported point of railway station).

Trade Area Analysis (Map Info Vertical Mapper 11.0) permitted to classify ten classes of distance from the railway station (class 10 is the nearest to railway station and class 1 is the fairest). Weight average of the area of commune were applied to compute an index per commune:

$RSDI = (\Sigma_{c=1-10} (A_c * C)) / A_{tot}$

With C the value of the class, a_c is the area covered by the class c, and A_{tot} is the total area of the commune.

Range from 1 to 10, no value = -999

Normalization (from 1 to 10): $RSDI_n = 1 + 9 * RSDI / 10$

3.2.2.7 Infrastructure Adaptive Capacity Index (AC_INFR)

The overall Infrastructure component of adaptive capacity (AC_INFR) is measured as:

AC_INFR = (RDI_n + HQI_n + PBI_n + EHI_n + $TWTI_n$ + $RSDI_n$) / 6

Range from 1.29 to 8.28, no value = -999

Normalization (from 1 to 10): AC_INFR_n = 1 + 9 * (AC_INFR – 1.29) / (8.28 – 1.29)

3.2.3 Economic adaptive capacity component

The economic component of adaptive capacity is strictly linked with the income per capita, the economic growth rate, save bank savings, debt per capita and the availability of jobs. Given the contest of Vietnam is difficult assess the income per capita of the population, was selected a proxy to measure the richness (or poverty) of the local communities. The availability of jobs is valuated as the percentage of unemployed people. Finally, no data exist on bank savings or debt per capita at commune level, that were not assessed in the present study.

The data on economic adaptive capacity were mined from the GSO population census 2009.

3.2.3.1 Unemployed Rate Index (URI)

Community with large part of unemployed population are less able to adapt to stress, as the unemployed people rely completely on the aids suppliers after a natural disaster. (Cross, 2001).

Data source from General Statistic Office of Vietnam 2009 population census

URI = percentage of people unemployed

Measurement unit = percentage of unemployed people

Range from 0.21 to 59.43, no value = -999

To normalize the value an inverse normalization was applied (from 1 to 10), and thus: URI_n = 10 - 9 * (URI – 0.21) / (59.43 – 0.21)

3.2.3.2 Poor Housing Index (PHI)

"I don't know what I could do - if I have money everything is easy" (interview CL7, My Ngai). (Few and Tran, 2010). Poverty is a crucial element of vulnerability in rural Vietnam. A large number of poor households increase the number of dependant people and therefore, increase the vulnerability of a commune. After a disaster, the rich get richer, the poor, poorer and the access to opportunities within the social entity are unequal and indirectly proportional to the occurrence of natural disasters (the less opportunities, the more vulnerability, the more affected by natural disasters) (Alcantara-Ayala, 2002). The percentage of weak homes was used as proxy of the poverty level of a commune.

Data source from General Statistic Office of Vietnam 2009 population census.

PHI = percentage of weak house (PWH)

Measurement unit = percentage of weak house

Range from 0 to 94.35, no value = -999

To normalize the value an inverse normalization was applied (from 1 to 10), and thus: PHI_n = 10 - 9 * PHI / 94.35

3.2.3.3 Economic Adaptive Capacity Index (AC_ECON)

The overall economic component of adaptive capacity index (AC_ECON) is measured as:

AC_ECON = (URI_n + PI_n) / 2

Range from 4.50 to 9.92, no value = -999

3.2.4 Social adaptive capacity component

According to Morrow (1999) special needs populations (young people, infirm, old people, homeless and women), while difficult to identify and measure, are disproportionately affected during disasters and, because of their invisibility in communities, mostly ignored during recovery. Moreover, large families (ratio population divided households) have a higher adaptive capacity than a smaller family. The adaptive capacity is influence also from ethnicity parameter, as usually minority are poorest (and thus less able to adapt to natural hazards) and often emarginated from the governmental subsides and are not supported from ad hoc legislation. Finally, the instruction play a pivotal role in the capacity of adaptation.

The data on social adaptive capacity were get from the GSO population census 2009.

3.2.4.1 Gender Rate Index (GRI)

As above mentioned women are a part of population that cannot adapt easily to natural stress, because in the traditional society they have to take care to the family and have no time to dedicate to themselves. Data source from General Statistic Office of Vietnam 2009 population census.

GRI = women / total population

Measurement unit = percentage of women

Range from 44.73 to 58.92, no value = -999

To normalize the value an inverse normalization was applied (from 1 to 10), and thus: GRI_n = 10 - 9 * (GRI – 44.73) / (58.92 – 44.73)

3.2.4.2 Underage People Index (UPI)

The underage people go to school, and a natural disaster lead to generally an interruption in the schooling curriculum. Furthermore they may become orphan and have difficulties to get income. Data source from General Statistic Office of Vietnam 2009 population census.

UPI = people under 18 years old / total population

Measurement unit = percentage of people younger than 18 years old

Range from 15.88 to 59.31, no value = -999

To normalize the value an inverse normalization was applied (from 1 to 10), and thus: UPI_n = 10 - 9 * (UPI – 15.88) / (59.31 – 15.88)

3.2.4.3 Elder People Index (EPI)

The people above 60 years old have generally no personal income, resulting full dependant to other people. Data source from General Statistic Office of Vietnam 2009 population census.

EPI = people above 60 years old / total population

Measurement unit = percentage of people older than 60 years old

Range from 1.68 to 21.97, no value = -999

To normalize the value an inverse normalization was applied (from 1 to 10), and thus: EPI_n = 10 - 9 * (EPI – 1.68) / (21.97 – 1.68)

3.2.4.4 Percentage of Ethnic Minority Index (PEMI)

Adaptive Capacity is diminished by imposes language and cultural barriers that affect the access to post-disaster funding. Moreover, minority are marginalized leading to leave them the less suitable area for agriculture and for residential location (Pulido, 2000; Peacock et al., 2000). Therefore commune with large part of minority population have a lower adaptive capacity. Data source from General Statistic Office of Vietnam 2009 population census.

PEMI = Not Kinh people / total population

Measurement unit = percentage of people belong to ethnic group different from Kinh (Vietnamese)

Range from 0 to 100, no value = -999

To normalize the value an inverse normalization was applied (from 1 to 10), and thus: $PEMI_n$ = 10 - 9 * PEMI / 100

3.2.4.5 Family Size Index (FSI)

Community with large family generally experiment a higher growth rate, that lead to lack of available quality housing, natural resources and, furthermore, the social services network may not have had time to adjust to increased populations (Morrow, 1999). Moreover, large family have a higher number of dependant people. Was not possible assess directly the demographic growth rate, we measure it as the ratio between total population and the number of households. Data source from General Statistic Office of Vietnam 2009 population census

FSI = population / number of households

Measurement unit = people / households

Range from 2.63 to 7.50, no value = -999

To normalize the value an inverse normalization was applied (from 1 to 10), and thus: FSI_n = 10 - 9 * (FSI – 2.63) / (7.50 – 2.63)

3.2.4.6 Alphabetization Rate Index (ARI)

High education level enhance the ability to cope with climate change and natural disasters, as generally reported in large part of literature (Cardona, 2005). Education is linked to socioeconomic status, with higher educational attainment resulting in greater lifetime earnings. Lower education constrains the ability to understand warning information and access to recovery information. Data source from General Statistic Office of Vietnam 2009 population.

ARI = people can read and write / total population

Measurement unit = percentage of people that can read and write

Range from 26.65 to 92.80, no value = -999

Normalization (from 1 to 10): ARI_n = 1 + 9 * (ARI – 26.65) / (92.80 – 26.65)

3.2.4.7 Average Schooling Years Index (ASYI)

The same the average of schooling year is one more proxy to assess the education level of a community. Data source from General Statistic Office of Vietnam 2009 population

$ASY = (\sum_{n=1}^{11}(a_n * \mathrm{n}))$ / 100

With a_n the percentage of people that frequent n years of school, and n the years of school

Measurement unit = average schooling years

Range from 0.43 to 5.27, no value = -999

Normalization (from 1 to 10): ARI_n = 1 + 9 * (ASYI – 0.43) / (5.27 – 0.43)

3.2.4.8 Social Adaptive Capacity Index (AC_SOCI)

The overall social component index of adaptive capacity (AC_SOCI) where calculated as the mathematical average of the 7 indicators above presented

$AC\_SOCI = (GRI_n + UPI_n + EPI_n + PEMI_n + FSI_n + ARI_n + ASYI_n) / 7$

Range from 3.31 to 8.27, no value = -999

3.2.5 Natural adaptive capacity component

The capital natural of a system is an important resource that increase the capacity to adapt to climatic stress a community. Several are the possible indicators. An important indicators developed was the climatic stability in the last century. Adopting the dataset from 1901 to 2009 was measured the trend for each location and established a simple proxy to determine the climatic stability of a region rather than another. The potential agriculture land is also important to determining the capacity of land to be farmed and therefore determine the capacity to adapt to climate stress that can reduce the productivity of culture. Furthermore, given the rural conditions of the studied area was selected the availability of agriculture land per people and the availability per people of protected forest land and forest with huge biomass.

The data used to compute the indicator of natural adaptive capacity was collected for the climatic data from the CRU TS 3.1 dataset (Mitchell and Jones, 2005; and Mitchell and Jones, in preparation), the slope was computed from ASTER GDEM, while for the agriculture and forested land coverage were largely taken from land use map 2010 (MONRE) and forest cover map 2009 (FIPI) at scale 1:50,000, population data from GSO general census 2009.

3.2.5.1 Climate Variability Index (CVI)

Climatic variability to the last century climatic stimulus is a proxy of ecosystem fragility. Therefore, an inverse normalization of CVI represents a component of adaptive capacity of the natural ecosystem.

Data source from CRU TS 3.1 (Mitchell and Jones, 2005; and Mitchell and Jones, in preparation), from 1901 to 2009 with resolution of 30 minute of arc (about 60 km). The used parameter were: monthly Total precipitation, rainy day frequency per months, daily mean temperature, monthly average daily maximum and minimum temperature.

Traditional, advanced statistics, such as signal-to-noise ratios and optimal signal detection, have been used to investigate the changes that occur on different time scales for each point. Use of these statistics often proves insightful for single points, but must be adjusted to optimize the signal for all other location. Simple statistical methods, such as linear trends, are still useful for investigating changes in climatic patterns. Slopes of the linear fits to the time series of climatic data provide a simple picture of changes that have occurred at any location over an extended period of time (Boyles and Raman, 2003). After a universal linear kriging interpolation (Collins and Bolstad, 1996; Goodale et al., 1998), a summation of the absolute value of monthly linear trend for the five parameter was performed:

$CVI = (\sum_{i=1-12} |pre_i| * \sum_{i=1-12} |wet_i| * \sum_{i=1-12} |tmm_i| * \sum_{i=1-12} |tmx_i| * \sum_{i=1-12} |tmn_i|) / 12$

High values of CVI highlight a strong climate change in the last century and therefore the likelihood of a climatic stress of similar magnitude in the next century. Vice versa low CVI values indicate a stable climatic situation in the last century and therefore in the future. A stable climatic environment facilitate the adaptation of the local community.

Measurement of unit = absolute percentage of variability for the five meteorological parameters examined

Range from 1.00 to 9.73, no value = -999

To normalize the value an inverse normalization was applied (from 1 to 10), and thus: $CVI_n = 10 - 9 * (CVI – 1.00) / (9.73 – 1.00)$

3.2.5.2 Flat Land Index (FLI)

High percentage of flat or with moderate slope (minor than 8.5°) increase the adaptive capacity because decrease the probability of soil erosion, and moreover flat land can be farmed comfortably and therefore, increase the buffer of natural resources unexploited from the community (Heltberg et al., 2008). Such threshold was identified as the slope rate that differencing the land easily to be farmed with cereals from the sloppy land that request technical measures to be cultivated.

Source of data: The topographic maps available in Vietnam was developed in Microstation format (CAD). Such dataset did not present the elevation quote associated to the contour figures. Therefore, the ASTER Global Digital Elevation Model (GDEM) was used to develop the topographic parameter. Such Model were released by NASA and Japan’s Ministry of Economy, Trade and industry on June 29, 2009. The GDEM is produced with 30 meter postings. From DEM was identified all the area with a slope minor than 8.5°.

FLI = hectare of land with slope minor than 8.5° / total area of commune (hectare)

Measurement unit = Percentage of commune land with slope minor than 8.5°

Range from 2.32 to 100, no value = -999

Normalization (from 1 to 10): FLI_n = 1 + 9 * (PFL –2.32) / (100.00 – 2.32)

3.2.5.3 Agriculture Land Availability Index (ALAI)

The available agriculture land is an important natural resource. Households with small amount of land pro capita are less able to undertake adaptation’s strategies to natural hazards. For example, prior to the Irish Potato Famine, many peasants were unable to afford draught animals or ploughs and did not have access to enough land to diversify their crops (Fraser, 2007).

Data source for population was the GSO population census 2009, while the agriculture land surface data was taken from Land use map (MONRE, 2010).

ALAI = hectare of agriculture land * 1000 / population

Measurement unit = hectare of farmed land per one thousand persons

Range from 0 to 6734.82 hectare / thousand persons, no value = -999

Normalization (from 1 to 10) for rural area: $ALAI_n$ = 1 + 9 * ALAI / 6734.82

3.2.5.4 Protected and Natural Forest Land Availability Index (PNFLAI)

Commune with high percentage of forest cover land has higher capacity to adapt to climate stimuli because its natural resources are not yet over exploited and the community hold a buffer of resources available to be used during environmental crisis. Furthermore, land with large forest cover are less exposed to natural disaster as soil erosion, landslide, etc... (Hamilton, 1992).

PNFLAI = hectare of natural or protected forest *1000 / population

Measurement unit = hectare of natural or protected forest land per thousand persons

Range from 0 to 23861.53 hectare / thousand persons, no value = -999

Normalization (from 1 to 10): $PNFLAI_n$ = 1 + 9 * PNFLAI / 23861.53

3.2.5.5 Natural Adaptive Capacity Inxed (AC_NATU)

The overall nature component index of adaptive capacity (AC_NATU) where calculated as the mathematical average of the 7 indicators above presented

AC_NATU = (CVI_n + FLI_n + $ALAI_n$ + $PNFLAI_n$) / 4

Range from 1.08 to 7.63, no value = -999

3.3 Vulnerability

The vulnerability was calculated as the ratio between Sensibility and Adaptive Capacity.

Therefore a general adaptive capacity had to be computed before. To obtain this global value of adaptive capacity the five different component of adaptive capacity were combined according to the weight established during the Analytical Hyerarchical Process (AHP) in each provinces. Here the results of AHP are simply reported in the table below.

Table 12: Adaptive capacity component and their weight according to the different province perception

Components	Lao Cai	Yen Bai	Phu Tho
Institutional adaptive capacity	0.42	0.19	0.46
Infrastructure adaptive capacity	0.17	0.11	0.22
Social adaptive capacity	0.17	0.38	0.19
Economic adaptive capacity	0.17	0.18	0.06
Nature adaptive capacity	0.07	0.13	0.08

AC_Lao Cai = 0.42 * AC_INST + 0.17 * AC_INFR + 0.17 * AC_SOCI + 0.17 * AC_ECON + 0.07 * AC_NATU

AC_Yen Bai = 0.19 * AC_INST + 0.11 * AC_INFR + 0.38 * AC_SOCI + 0.18 * AC_ECON + 0.13 * AC_NATU

AC_Phu Tho = 0.46 * AC_INST + 0.22 * AC_INFR + 0.19 * AC_SOCI + 0.06 * AC_ECON + 0.08 * AC_NATU

The weight wrote in this equation were reported in the GIS layer and a calculation was performed.

Finally, the Vulnerability was calculated as the root square of ten multiplied the Sensibility and divided by each specific provincial adaptive capacity (AC_i), as in the following formula:

VULN = $(10 * \text{Sensibility} / \text{AC\_i})^{0.5}$

Where i represent the province studied

Range from 1.62 to 3.97, no value = -999

The mathematical artifice to multiple by ten and compute the root square was introduced to report the theoretical value of Vulnerability to a range between 1 and 10. Without this step the theoretical range would have been much larger (from 0.1 to 100), invalidating the relationship with hazard scale (from 1 to 10) and therefore the subsequent calculation of risk index.

3.4 Hazards

To compute the different hazard level were performed the following general procedure adapted with different index to each studied hazard.

Preliminary, was calculated the grid file for each “n” index chosen for compute the hazard index. Such “n” grid was then classified in ten class according the scientific literature if available or to fit logically the level of the hazard. Later, a grid calculation operation with all the selected “n” index grid were performed to calculate the hazard’s grid. Finally, the hazard’s grid were trimmed with the administrative boundary to produce one hazard’s grid for each administrative unit (619). All this 619 hazard’s grid were exported in ASCII format (txt), and thus read with a script in AWK to calculated the average hazard value for each administrative unit, according the formula:

HAZARD AVERAGE LEVEL = $\sum_{c=1}^{10}(a_c * \mathrm{C})) / A_{tot}$

With C the value of the hazard (from 1 to 10), a_c is the area covered by the hazard class c, and A_{tot}

is the total area of the administrative unit. This operation allowed to compute for each administrative unit a specific hazard level, that can be reported in the vector administrative database and therefore, compared with the socio-economic indicators.

3.4.1 Drought

The World Meteorological Organization (WMO, 1986) defines drought “a sustained, extended deficiency in precipitation.” The Food and Agriculture Organization (FAO, 1983) of the United Nations defines a drought hazard as “the percentage of years when crops fail from the lack of moisture.” However, drought definitions vary, depending on the variable used to describe the drought: (i) meteorological drought is defined as a lack of precipitation over a region for a period of time (Eltahir, 1992); (ii) Hydrological drought is related to a period with inadequate surface and subsurface water resources for established water uses of a given water resources management system (Clausen and Pearson, 1995); (iii) Agricultural drought, usually, refers to a period with declining soil moisture and consequent crop failure without any reference to surface water resources. (FAO, 1983); (iv) Socio-economic drought is associated with failure of water resources systems to meet water demands and thus associating droughts with supply of and demand for an economic good (water) (AMS, 2004).

The most common drought indicators is the SPI (Standardized Precipitation Index) (McKee *et al.*, 1993). However, we couldn’t use such indicators in the present study. First of all the daily precipitation data are not available for a long period, statistically meaningful, to compute SPI. Furthermore, the drought in Vietnam belong mainly to the agricultural and hydrological classes.

To overcome the first issue, and calculate a meteorological indicator of drought, were adopted annual indicators as the Annual Mean Aridity Index AMAI (Li et al., 2000) and the Precipitation Concentration Index (PCI) that is a measure of precipitation concentration during the year (Luis et al, 2011). PCI was proposed as an indicator of rainfall concentration and rainfall capacity to contribute to the soil erosion phenomena (Michiels et al., 1992). Oliver (1980) suggested to classify the PCI in the following way: PCI values less than 1 represent a uniform precipitation distribution; PCI values from 1 to 1.5 denote a moderate precipitation concentration; values from 1.6 to 2 denote irregular distribution; and values above 2 represent a strong irregularity (i.e., high precipitation concentration) of precipitation distribution.

The second issue, implies that such approach is not completed. To define better the drought we shall to collect soil map (actually not available at a good resolution) to evaluate soil moisture, rivers flow data (or extrapolate it modelling the rivers system) and the map of source of irrigation water and irrigation channel, not fully available through the whole studied area.

3.4.1.1 Meteorological indicator of drought (METEOR)

As mentioned above were used the combination of two grid, namely AMAI and PCI:

AMAI (Annual Mean Aridity Index) = $((1/12) \sum_{i=1-12} (0.0018 * (Tmp_i + 25)2*((1 – Hmr_i/100)/Pre_i)$

Where Tmp is the daily mean temperature (in °C) in the month i; Hmr is the daily mean relative humidity (in %) in the month i; and Pre is the daily mean precipitation (in mm) in the month i.

$PCI = 10 \sum_{i=1-12} (Pre_i)^2 / (\sum Pre_i)^2$

Where Pre is the daily mean precipitation (in mm) in the month i. It ranges from 1.32 (moderate bi-seasonality) to 1.75 (strong bi-seasonality).

The source of data was the WorldClim (Hijmans et al, 2005) dataset, with resolution of 1 km^2. Variables included are monthly total precipitation, and monthly mean, minimum and maximum temperature, representing the period 1950-2000. For relative humidity was used the CRU CL 2.0 dataset (resolution 20 Km) from the Climatic Research Unit of East Anglia University.

The dataset were homogenised at the some resolution using ANUSPLIN software. It is a program for interpolating noisy multi-variate data using thin plate smoothing splines. We used latitude, longitude, and elevation as independent variables.

No measurement unit.

To compute the METEOR grid index was used the following equation:

$METEOR = AMAI * PCI^2$

The obtained values ranging from $1.59 * 10^{-2}$ to $6.14 * 10^{-2}$. The range were then divided in ten equal class reported in the following table:

Table 13: METEOR grid classification

Classes	From	To
1	0.0160	0.0205
2	0.0205	0.0250
3	0.0250	0.0296
4	0.0296	0.0341
5	0.0341	0.0387
6	0.0387	0.0432
7	0.0432	0.0478
8	0.0478	0.0523
9	0.0523	0.0569
10	0.0569	0.0614

3.4.1.2 Forest density (FOREST)

The forest density is inverse proportional to the potential drought index, because the vegetation keep the soil with higher moisture rate. To estimate the forest density were used the forest vector map updated in 2009 by the FIPI. The vector layer was transformed in a grid layer (namely, forest cover grid) with resolution at 30 meter and thus the grid was classified in ten classes according to the table reported below.

Table 14: FOREST grid classification

Classes	Typology
1	Rich forest Water surface
2	Regenerated forest with heavy biomass
3	Medium forest
4	Plantation and special forest Regenerated forest
5	Mix forest
6	Poor forest
7	Agriculture land Settlement and industrial land Bare land with sparse trees
8	Bare land with grass Bare land with bush
9	Bare land Rocky mountain with trees
10	Rocky mountain

3.4.1.3 Distance to river (RIVDIS)

The distance from the river is considered a proxy of availability of water for irrigation. To enhance this index could be included the rivers model for the study area's watershed. River network was obtained from land use map 2010 (MONRE). The vector layer were transformed in a grid layer to allow map algebra operation. The transformation was conducted with a resolution of 50 meters. The river distance grid was then classified according the following table.

Table 15: RIVDIS grid classification

Classes	From	To
1	0	100
2	100	250
3	250	500
4	500	750
5	750	1,000
6	1,000	2,000
7	2,000	3,000
8	3,000	4,000
9	4,000	5,000
10	5,000	> 5,000

3.4.1.4 Drought index (H_DROUG)

Overall Drought Index was calculated according the following formula:

H_DROUGHT = (2 * METEOR + FOREST + RIVDIS) / 4

The value of H_DROUG ranging from 1 to 8.7193

The average value for each commune (H_DROUG_c) was computed using the methodologies already descript (paragraph 3.4). Drought hazard range from 1 to 8.72

3.4.2 Lao wind

Lao Wind is an adiabatic descending wind blowing from West that trigger to decrease of relative humidity and increase maximum temperature. This conditions lead to a strong evapo-transpiration from the soil and therefore, increase soil aridity. The phenomena is not well studied and missing any organized measures of the frequency of the Lao Wind. It's known only the period of the year when the wind may blow from West: from April to September. It is considered that Lao Wind lead to an increase of temperature over 35 °C and a decrease of relative humidity under 55%. Therefore this two meteorological parameters were adopted to map the impact of Lao Wind. Moreover, the wind reach is maximum intensity at 3000 meter, and decrease at lower level of altitude. Therefore, a third topographical factor is added to represent the elevation. Finally the key parameter is the topographic landscape. As a matter of fact the Lao wind move along the valley. Therefore, to complete the research on such indicator we have to compute a Lagrange model of this wind. However, develop this model was not possible because lacking in any dataset explored the wind direction. Therefore, was not possible to elaborate a realistic model of Lao Wind impacts in the study area.

3.4.3 Frost

This natural hazard was reported only from authority of Lao Cai, anyway the assessment was conducted in the all studied area. Temperature's decrease could affect the normal development of farmed plants, furthermore, leading to disease outbreak.

Meteorological dataset of frosting event was used to evaluate the effect of latitude combined with topographical indicators: aspect (versant exposed North) slope (sloppy land receive less sun energy x surface unit, inversely proportional to the cosine of slope degree) and elevation.

3.4.3.1 Frost frequency (FRSFRE)

Source of data CRU CL 2.0 (resolution 20 Km). The summation of month average frosting day was used: FRS = $\sum_{i=1-12}$ (Frs_i)

It range from 0 to 36.9713 day of frost per year.

3.4.3.2 Elevation (ELEVAT)

Source of data is the ASTER Global Digital Elevation Model (GDEM), released by NASA and Japan's Ministry of Economy, Trade and industry on June 29, 2009. The GDEM is produced with 30 meter postings. The elevation values was classified in ten classes according to the following table:

Table 16: ELEVAT grid classification for computing frost hazard

Classes	From	To
1	0	200
2	200	400
3	400	600
4	600	800
5	800	1,000
6	1,000	1,250
7	1,250	1,500
8	1,500	1,750
9	1,750	2,000
10	2,000	> 2,000

Measurement unit: meter

3.4.3.3 Slope (SLOPPY)

Source of data: ASTER Global Digital Elevation Model (GDEM), released by NASA and Japan's Ministry of Economy, Trade and industry on June 29, 2009. The GDEM is produced with 30 meter postings. From DEM was derived the slope map. Sloppy versant receive less solar radiation in than flat area. The solar radiation received from a surface is inversely proportional to the cosine of slope degree of the surface.

Table 17: SLOPPY grid classification for computing frost hazard

Classes	From	To
1	0	10
2	10	15
3	15	20
4	20	25
5	25	30
6	30	35
7	35	40
8	40	50
9	50	60
10	60	90

Measurement unit: slope degree

3.4.3.4 Aspect (ASPECT)

Source of data: ASTER Global Digital Elevation Model (GDEM), released by NASA and Japan's Ministry of Economy, Trade and industry on June 29, 2009. The GDEM is produced with 30 meter postings. From DEM was derived the aspect map. The versant exposed to North are prone to frosting.

Table 18: ASPECT grid classification for computing frost hazard

Classes	From	To
1	162	198
2	144	162
	198	216
3	126	144
	216	234
4	108	126
	234	252
5	90	108
	252	270
6	72	90
	270	288
7	54	72
	288	306
8	36	54
	306	324
9	18	36
	324	342
10	0	18
	342	360

Measurement unit: degree from North.

3.4.3.5 Frost Index (H_FROST)

Overall Frost Hazard Index was modified from (Gessler et al. 2000):

H_FROST = (FRSFRE / 36.9713) * (3*ELEVAT + SLOPPY + ASPECT) / 5

H_FROST ranging from 0 to 9.6

The FRSFRE was divided by the maximum value registered for it (36.9713) in order to normalize this factor between 0 and 1.

The average value for each commune (H_FROST_c) was computed using the methodologies already descript (paragraph 3.4).

3.4.4 Wildfire

Wildfires are a serious problem affecting many terrestrial ecosystems and causing substantial economic damage (Butry et al., 2001). Wildfires particularly create damage in the wildland–urban interfaces that total hundreds of millions of dollars annually in the United States (Mercer and Prestemon, 2005) and can also affect human life severely: around 100 people were killed by wildfire in Europe in 2007, (Lampin-Maillet et al., 2009).

The wildfire hazard mapping model adopted was develop by Erten et al. (2002). It consider a fuel hazard component, the vegetal biomass, that depending on the density of forest and the type of forest (deciduous forest produce much more fuel than evergreen plant), and even from the typical moisture of vegetal species. Then there is a topographical hazard component (slope and aspect), and finally a "human" hazard component.

3.4.4.1 Fuel component (FUEL)

The fuel component for assessing wildfire hazard was derived using forest map updated in 2009 by the FIPI. There was no classification of the type of the forest, therefore was not possible gave different weight to different type of forest. Water bodies areas do not affect the forest fire risk. These zones have no weights in determination of fire rating class. The vector map was gridded with a resolution of 30 meter. The classification of different type of forest coverage was compute according the following table, modified by Erten et al. (2002) to adapt it to the reported value in the forestall map collected.

Table 19: FUEL grid classification for wildfire hazard calculation

Classes	Typology
1	Rocky mountain without trees Water surface
2	Rocky mountain
3	Plantation and special forest
4	Rich forest Medium forest Regenerated forest Regenerated forest with heaving biomass
5	Poor forest
6	Mix forest
7	Bare land with sparse trees Bare land
8	Settlement and industrial land
9	Agriculture land
10	Bare land with grass Bare land with bush

3.4.4.2 Topographic component

Fire travels most rapidly up-slopes and least rapidly down-slopes. Slope classes were created according to this rule. Aspect was assigned equal weight with slope. Since the sunlight is much more reflected on the slopes in the South, fire breaks out fast and spreads in the South sides, and secondary on the West side. The classes for this two factors are reported in the following table:

Table 20: ASPECT and SLOPPY grid classification for wildfire hazard calculation

	ASPECT		SLOPPY	
Classes	From	To	From	To
1	0.0	22.5	0.0	2.5
	345.0	360.0		
2	22.5	45.0	2.5	5.0
	330.0	345.0		
3	45.0	67.5	5.0	7.5
	315.0	330.0		
4	67.5	90.0	7.5	10.0
	300.0	315.0		
5	90.0	105.0	10.0	20.0
	280.0	300.0		
6	105.0	120.0	20.0	25.0
	260.0	280.0		
7	120.0	135.0	25.0	30.0
	240.0	260.0		
8	135.0	150.0	30.0	35.0
	220.0	240.0		
9	150.0	165.0	35.0	60.0
	200.0	220.0		
10	165.0	200.0	60.0	90.0

The source of data: ASTER Global Digital Elevation Model (GDEM), released by NASA and Japan's Ministry of Economy, Trade and industry on June 29, 2009. The GDEM is produced with 30 meter postings. Measurement unit: degree from North for aspect and degree for sloppy.

3.4.4.3 Human component

Distance from roads (ROADIS) and settlements (SETDIS) were evaluated to determine the human component to the hazard. The hazard factor decreases farther from these places. It means that a zone close to these places were evaluated a higher hazard rating according to the following table.

Table 21: ROADIS and SETDIS grid classification for wildfire hazard calculation

	ROADIS		SETDIS	
Classes	From	To	From	To
1	> 450	450	> 5,000	5,000
2	450	400	5,000	4,000
3	400	350	4,000	3,500
4	350	300	3,500	3,000
5	300	250	3,000	2,500
6	250	200	2,500	2,000
7	200	150	2,000	1,500
8	150	100	1,500	1,000
9	100	50	1,000	500
10	50	0	500	0

The source of data for road network and settlement was the land use map from MONRE (2010) that was later gridded and classified.

Measurement unit: meter

3.4.4.4 Ethnic minority as proxy for slash and burn (ETMIPE)

According to the local knowledge of population a large driver of wildfire were the agriculture practise called "slash and burn". Such practise is illegal but is quite frequently conducted by ethnic minority. To include local knowledge within the calculation of wildfire hazard level, was considered the percentage of ethnic minority by commune. The data of GSO reported in a vector shapefile was gridded and later classified in ten equal class according to the following table.

Table 22: ETMIPE grid classification for wildfire hazard calculation

Classes	From	To
1	0	10
2	10	20
3	20	30
4	30	40
5	40	50
6	50	60
7	60	70
8	70	80
9	80	90
10	90	100

Measurement unit: percentage of ethnic minority on the total population.

3.4.4.5 Wildfire Index (H_WILDF)

The equation used in GIS (Erten *et al.*, 2002) to determine forest fire hazard places is shown in the equation below:

H_WILDF = (3 * FUEL + 2 * SLP + 2 * ASP + RIVDIS + SETDIS + ETMIPE) / 10

The average value for each commune (H_WILDF_c) was computed using the methodologies already descript (paragraph 3.4). Wildfire hazard range from 1 to 9.80

3.4.5 Flash flood

A flash flood is defined as a flood which follows shortly (i.e. within a few hours) after a heavy or excessive rainfall event (Sweeney, 1992). Flash floods are one of the most significant natural hazards and cause serious loss of life and economic damage. The average annual economic loss due to natural hazards over the world has been estimated at € 40 billion (Münich Re, 2003).

To assess the flash flood hazard level was adopted the FFPI (Flash flood Potential Index) developed by USGS. The index was modified as was not available in the study area a soil map with a good scale. (Smith, 2003). Such index use the slope degree of the versant, a tree density model and the land cover. We add an indicator of rainy concentration on annual base (Precipitation Concentration Index, PCI) to represent the rainy variation during the year, as this factor is very much more important in Vietnam than the area where the FFPI was developed. Unluckily daily or better hourly precipitation data were not available, to enhance the meteorological component of FFPI, therefore was used the PCI (Precipitation Concentration Index).

3.4.5.1 Slope (SLOPPY)

Slope value were classified in ten classes according to the following table. The SLOPPY score increases following and exponential law (exp (0.3+x)) as suggested by Smith (2003).

Table 23: SLOPPY grid classification for flash flood hazard calculation

Classes	From	To
1	0.0	4.2
2	4.2	5.8
3	5.8	7.4
4	7.4	9.0
5	9.0	10.6
6	10.6	12.2
7	12.2	13.8
8	13.8	15.4
9	15.4	17.0
10	17.0	> 17.0

Measurement unit: degree.

Source of data: ASTER Global Digital Elevation Model (GDEM), released by NASA and Japan's Ministry of Economy, Trade and industry on June 29, 2009. The GDEM is produced with 30 meter postings. From DEM was derived the aspect map

3.4.5.2 Land cover (LANCOV)

The land use map 2010 of MONRE was classified in nine classes according to the table below and gridded with a resolution of 100 meter. The classification follow the criteria that urban and anthropic lands are much prone to flash flood than natural land, especially if the land is leave at pristine conditions. The lower scores were assigned to water surface.

Table 24: LANCOV grid classification for flash flood hazard calculation

Classes	Typology
1	Water surface
2	Wetland
3	Perennial forest
4	Mix forest
5	Poor forest
6	Agriculture and shrub
7	Barren land
8	Rural residential
9	Urban residential
10	Industrial land

3.4.5.3 Forest density (FORCOV)

The forest density is inverse proportional to the potential flash flood index, because higher uptake rate of moisture. To estimate the forest density were used the forest map updated in 2009 by the FIPI. The forest cover was classified in ten classes according to the table reported below.

Table 24: FORCOV grid classification for flash flood hazard calculation

Classes	Typology
1	Rich forest
2	Regenerated forest heaving biomass
3	Special use and plantation forest Medium forest Regenerated forest
4	Mix forest
5	Poor forest
6	Rocky mountain with trees Bare land with sparse trees
7	Agriculture land
8	Bare land with bush Bare land with grass
9	Settlement and industrial land
10	Rocky mountain Bare land Water surface

3.4.5.4 Precipitation Concentration Index (PCI)

The precipitation concentration index, already used for drought was used to assess the rainfall temporal concentration. The PCI grid was classified in equal classes according to the following table:

Table 25: PCI grid classification for flash flood hazard calculation

Classes	From	To
1	1.24	1.29
2	1.29	1.34
3	1.34	1.39
4	1.39	1.44
5	1.44	1.49
6	1.49	1.54
7	1.54	1.59
8	1.59	1.64
9	1.64	1.69
10	1.69	1.74

Source of data WorldClim dataset (resolution 1 square Km).

3.4.5.5 Flash flood Potential Index (H_FLASH)

The equation used in GIS to determine flash flood potential index is shown in the equation below (Smith, 2003):

H_FLASH = (2 * SLOPPY + 2 * FORCOV + 2 * LANCOV + PCI) / 7

The hazard value range from 1.26 to 9.67.

Then, the resulting grid file was then elaborated with AWK script to obtained the average flash flood hazard level for each administrative unit.

3.4.6 Landslide

Landslides are important natural hazards and an active process that contributes to erosion and landscape evolution. Different natural phenomena and human disturbances trigger landslides. Natural triggers include meteorological changes, such as intense or prolonged rainfall or snowmelt, and rapid tectonic forcing, such as earthquakes or volcanic eruptions. Human disturbances include land use changes, deforestation, excavation, changes in the slope profile, irrigation, etc. (Guzzetti et al., 2005).

The assessment of landslide hazard level was performed according to Chau et al. (2003) for the climatic factors and Nefeslioglu et al. (2011) for all the other factors. As a matter of fact Chau et al. (2003) results showed a strong correlation between the mean month rainfall quantity and the number of landslide. Therefore, as first indicator for landslide was selected the mean monthly precipitation. The other factor influencing landslide are grouped in three sub-categories: topographic, hydro-geologic and human. Topographic factor used were slope and aspect, while human factors was distance to road and land use. The hydro geologic factors included the topographic wetness index, the slope length factor and the Stream Power Index. Geological layer was missing as the area is not covered consistently from a uniform and detailed geological map.

3.4.6.1 Precipitation (PRECIP)

Source of data was Worldclim dataset (already previously introduced). The data had a definition of one square kilometre. The data were classified according the following table.

Table 26: PRECIP grid classification for landslide hazard calculation

Classes	From	To
1	0	1,500
2	1,500	1,600
3	1,600	1,700
4	1,700	1,800
5	1,800	1,900
6	1,900	2,000
7	2,000	2,100
8	2,100	2,200
9	2,200	2,300
10	2,300	> 2,300

3.4.6.2 Slope (SLOPPY)

Slope value were classified in six classes according to the table below (Nefeslioglu et al., 2011).

Table 27: SLOPPY grid classification for landslide hazard calculation

Classes	From	To
1	0	5
2	5	8
3	8	10
4	10	13
5	13	45
6	45	15
7	15	40
8	40	30
9	30	20
10	20	> 20

Measurement unit: degree

Source of data: ASTER Global Digital Elevation Model (GDEM), released by NASA and Japan's Ministry of Economy, Trade and industry on June 29, 2009. The GDEM is produced with 30 meter postings.

3.4.6.3 Aspect (ASPECT)

The versant exposed to North and North West are considered the one with higher moisture. Slope with high moisture are prone to landslide phenomena.

Table 28: ASPECT grid classification for landslide hazard calculation

Classes	From	To
1	157.5	193.5
2	135.0	157.5
	193.5	207.0
3	112.5	135.0
	207.0	220.5
4	90.0	112.5
	220.5	234.0
5	67.5	90.0
	234.0	247.5
6	45.0	67.5
	247.5	261.0
7	22.5	45.0
	261.0	274.5
8	0.0	22.5
	274.5	288.0
9	288.0	301.5
	337.5	360.0
10	301.5	337.5
	157.5	193.5

Measurement unit: degree from North.

Source of data: ASTER Global Digital Elevation Model (GDEM), released by NASA and Japan's Ministry of Economy, Trade and industry on June 29, 2009. The GDEM is produced with 30 meter postings.

3.4.6.4 Land forest coverage (FOREST)

The forest map 2009 of FIPI was classified according to the table below and gridded with a resolution of 100 meter. The classification follow the criteria that anthropic lands and bare lands are much prone to landslide than forested lands.

Table 29: FOREST grid classification for landslide hazard calculation

Classes	Typology
1	Rich forest Water surface
2	Regenerated forest heaving biomass
3	Medium forest
4	Special use and plantation forest Regenerated forest
5	Mix forest
6	Poor forest
7	Agriculture land Bare land with sparse trees Settlement and industrial land
8	Bare land with bush Bare land with grass
9	Rocky mountain with trees Bare land
10	Rocky mountain

3.4.6.5 Distance to road (ROACUT)

Road network was deducted from land use map 2010 of MONRE. The proximity of road can trigger to landslide as road cutting the versant causing landslide. A buffer operation was conducted at the road layer and then the classification reported in the table below was adopted.

Table 30: ROACUT grid classification for landslide hazard calculation

Classes	From	To
1	200	> 200
2	175	200
3	150	175
4	125	150
5	100	125
6	75	100
7	50	75
8	30	50
9	10	30
10	0	10

3.4.6.6 Topographic Wetness Index (TWI)

The last topographic attribute evaluated in the study is the topographic wetness index (TWI). Moore et al. (1991) also suggest an equation to calculate the TWI. This suggestion assumes steady–state conditions and uniform soil properties (i.e., transmissivity is constant throughout the catchment and equal to unity):

TWI = ln (As / tan B)

Where As is the specific catchement area , and B is the slope gradient. The TWI values was than normalized between 0 and 1.

This equation predicts zones of saturation where the specific catchment is large (typically in converging segments of landscapes) and is small (at base of concave slopes where slope gradient is reduced) (Wilson and Gallant, 2000). The main limitation of this approach is to accept the unique soil conditions. However, Wood et al. (1990) emphasized that the change in topographic attributes is more effective on the wetness characteristics than change in soil characteristics,

3.4.6.7 Stream Power Index (SPI)

The stream power index (SPI) is defined as a measure of erosive power of flowing water based on the assumption that discharge is proportional to specific catchment area (Wilson and Gallant, 2000). Moore et al. (1991) suggests an equation to calculate the SPI considering the assumption given here:

SPI = As × tan B.

Where As is the specific catchement area , and B is the slope gradient. The SPI values was than normalized between 0 and 1.

3.4.6.8 Length Slope factor (LSf)

The sediment transport capacity index is derived from unit stream power theory and is equivalent to the length–slope factor in the Revised Universal Soil Loss Equation (RUSLE) in certain circumstances (Wilson and Gallant, 2000). The equation (Eq. (8)) proposed by Moore and Burch (1986) was used to calculate the sediment transport capacity index.

$LS = (m + 1) * (As / 22.13)^m * (\sin B / 0.0896)^n$

where, As is the specific catchment area, B is the slope gradient, and the values of m and n are given as 0.4 and 1.3 by Wilson and Gallant (2000). The LSf values was than normalized between 0 and 1.

3.4.6.9 Landslide Index (H_LANDS)

The equation used in GIS to determine landslide susceptibility index is shown in the equation below, (modified by Nefeslioglu et al., 2011):

H_LANDS = (SPI + TWI + LSf + 1) / 3 + (2 * SLOPPY + 2 * ASPECT + 2 * FOREST + PRECIP + ROACUT) / 11

It range from 1 to 9.055

The H_LANDS index grid file was then elaborated with AWK script to obtained the average landslide hazard level value for each administrative unit.

3.4.7 Flooding

Hydrologists commonly define floods as any flow event that exceeds the normal banks of a river or stream (Leopold and Maddock, 1954). Floods are also defined by their return period or relative frequency as the maximum event for a given year in the long term (Barrows, 1948). Some attribute perceived increases in flood damage to the increased development within flood-prone areas, and conclude that there is little evidence of a connection between forest conversion and large-scale, extreme flooding (FAO and CIFOR, 2005 and Calder, 1993). Therefore, the magnitude of the influence of land use on flooding, and its specific mechanisms, remains the focus of much research and debate throughout the world.

The flooding assessment was conducted according to the method of Pradhan (2009) modified to overcome some missing information. Topographical indicators derived from DEM (slope, curvature, elevation and flow accumulation) jointly with distance to river buffer, land cover and precipitation was used to identify the area prone to flooding.

According to this procedure the flooding level were computed from the equation:

Z_Flood = - 17.9 (SLOPPY) - 56.2 * (CURVAT) + 5.37 (PRECIP) – 8 (ELEVAT) – 0.2 (RIVDIS) + LANCOV

With SLOPPY degree of slope between 0° and 90°; derived by the ASTER Global Digital Elevation Model (GDEM) released on June 29, 2009.

CURVAT negative curvatures represent concave, zero curvature represent flat and positive curvatures represents convex respectively; derived by the ASTER Global Digital Elevation Model (GDEM) released on June 29, 2009.

PRECIP annual mean precipitation in mm; derived by the Worldclim dataset, with resolution of 1 Km.

ELEVAT elevation quote in meter; derived by the ASTER Global Digital Elevation Model (GDEM) released on June 29, 2009.

RIVDIS distance to the river in meter; the river network was obtained from land use map 2010 (MONRE) and transformed from vector file to grid with a resolution of 30 meter.

LANCOV land cover, classified in ten classes according to the following table.

Table 30: LANDCO grid classification for flooding hazard calculation

Classes	Typology
1	Rocky mountain
2	Protected natural and planted forest
3	Natural forest land for production Unused hill upland
4	Perennial industrial trees Perennial orchard and others Planted productive forest land Special use forest
5	Land for reforestation Upland rice Upland land for annual crop
6	Agriculture land Annual farmed flat land
7	Permanent paddy land Other paddy Unused flat land Land for irrigation
8	Rural residential area Land with river, channels and streams
9	Urban residential area
10	Industrial land Mines and querries Water surface

Then, in order to perform the normalization, were applied the following formula:

H_FLOOD = 10 * exp (Z_Flood) / (1 + exp (Z_Flood))

H_FLOOD range from 0 to 10.

3.5 Risk

To compute the risk value was applied the following equation:

$RISK_{droug}$ = H_DROUG * VULN = R_DROUG, range from 0.81 to 6.91, no value = - 999

$RISK_{frost}$ = H_FROST * VULN = R_FROST, range from 0 to 4.75, no value = - 999

$RISK_{wildf}$ = H_WILDF * VULN = R_WILDF, range from 1.38 to 9.31, no value = - 999

$RISK_{flash}$ = H_FLASH * VULN = R_FLASH, range from 1.37 to 10.09, no value = - 999

$RISK_{lands}$ = H_LANDS * VULN = R_LANDS, range from 1.39 to 7.33, no value = - 999

$RISK_{flood}$ = H_FLOOD *VULN = R_FLOOD, range from 0 to 13.22, no value = - 999

The multi-hazard risk (see annex table 130) was computed as summation of the seven risk hazard specific introducing the weight system for hazard discussed during AHP activities in the three provinces and discussed before. The following table is modified from the result of AHP as is removed the Lao wind and his percentage is assigned proportionally to the other hazards.

Table 31: Hazard weight system after removing Lao Wind

Hazards	Lao Cai	Yen Bai	Phu Tho
Drought	3.3 %	14.3 %	34.4 %
Frost	5.5 %	6.1 %	6.7 %
Wildfire	7.7 %	9.2 %	5.6 %
Flash flood	37.3 %	15.3 %	26.7 %
Landslide	22.0 %	10.2 %	3.3 %
Flooding	24.2 %	44.9 %	23.3 %

Therefore:

$RISK_{Lao\ Cai}$ = (0.033 * R_DROUG + 0.55 * R_FROST + 0.77 * R_WILDF + 0.373 * R_FLASH + 0.22 * R_LANDS + 0.242 * R_FLOOD)

$RISK_{Yen\ Bai}$ = (0.143 * R_DROUG + 0.061 * R_FROST + 0.092 * R_WILDF + 0.153 * R_FLASH + 0.102 * R_LANDS + 0.449 * R_FLOOD)

$RISK_{Phu\ Tho}$ = (0.344 * R_DROUG + 0.067 * R_FROST + 0.056 * R_WILDF + 0.267 * R_FLASH + 0.033 * R_LANDS + 0.233 * R_FLOOD)

Each produced maps represent the indexes of risk, vulnerability or hazard divided in five category: (I) very low level, (II) low level, (III) average level, (IV) high level, and (V) very high level. The classification where performed applying a Jenks Natural Breaks optimization for each province and for each index. The Jenks Natural Breaks method is a data classification method designed to determine the best arrangement of values into different classes. This is done by seeking to minimize each class's average deviation from the class mean, while maximizing each class's deviation from the means of the other groups. In other words, the method seeks to reduce the variance within classes and maximize the variance between classes. Finally, a mean value for each index was computed among the different value of each province. The following table resume the indexes value reported in the maps above illustred.

Table 32: Classification (five categories) values for each indicators

Classification levels:	Very low		Low		Average		High		Very high	
Indexes	from	to	from	to	from	to	from	To	from	To
Adaptive Capacity – Institutional	0.000	3.557	3.557	4.467	4.467	5.320	5.320	6.270	6.270	10
Adaptive Capacity – Infrastructural	0.000	2.717	2.717	3.700	3.700	4.667	4.667	5.927	5.927	10
Adaptive Capacity – Economic	0.000	6.697	6.697	7.710	7.710	8.420	8.420	9.070	9.070	10
Adaptive Capacity – Social	0.000	4.890	4.890	5.697	5.697	6.493	6.493	7.227	7.227	10
Adaptive Capacity - Natural	0.000	3.033	3.033	3.770	3.770	4.380	4.380	5.213	5.213	10
Sensitivity	0.000	2.837	2.837	3.843	3.843	4.957	4.957	6.667	6.667	10
Vulnerability	0.000	2.240	2.240	2.603	2.603	2.943	2.943	3.347	3.347	10
Drought's hazard	0.000	2.000	2.000	4.000	4.000	6.000	6.000	8.000	8.000	10
Drought's hazard average	0.000	2.997	2.997	3.557	3.557	4.203	4.203	4.947	4.947	10
Drought's risk	0.000	8.080	8.080	9.983	9.983	12.027	12.027	14.463	14.463	100
Flash flood's hazard	0.000	2.000	2.000	4.000	4.000	6.000	6.000	8.000	8.000	10
Flash flood's hazard average	0.000	4.537	4.537	5.077	5.077	5.590	5.590	6.207	6.207	10
Flash flood's risk	0.000	11.990	11.990	14.083	14.083	16.433	16.433	18.877	18.877	100
Flooding's hazard	0.000	2.000	2.000	4.000	4.000	6.000	6.000	8.000	8.000	10
Flooding's hazard average	0.000	1.157	1.157	2.653	2.653	4.160	4.160	5.713	5.713	10
Flooding's risk	0.000	3.077	3.077	7.797	7.797	13.157	13.157	17.853	17.853	100
Frost's hazard	0.000	2.000	2.000	4.000	4.000	6.000	6.000	8.000	8.000	10
Frost's hazard average	0.000	0.243	0.243	0.697	0.697	1.357	1.357	2.550	2.550	10
Frost's risk	0.000	0.840	0.840	2.660	2.660	4.910	4.910	6.897	6.897	100
Landslide's hazard	0.000	2.000	2.000	4.000	4.000	6.000	6.000	8.000	8.000	10
Landslide's hazard average	0.000	4.167	4.167	4.490	4.490	4.840	4.840	5.237	5.237	10
Landslide's risk	0.000	10.503	10.503	12.030	12.030	13.553	13.553	15.227	15.227	100
Wildfire's hazard	0.000	2.000	2.000	4.000	4.000	6.000	6.000	8.000	8.000	10
Wildfire's hazard average	0.000	4.687	4.687	5.117	5.117	5.540	5.540	6.000	6.000	10
Wildfire's risk	0.000	11.833	11.833	13.800	13.800	15.783	15.783	18.487	18.487	100
Multihazard's risk	0.000	8.130	8.130	9.767	9.767	11.600	11.600	14.183	14.183	100

4. Conclusion and Recommendations

The present activity mapped the potential hazard that interest the study area. To complete the effort of the hazard mapping at a more detailed level (commune level) have to be implemented an intensive (high timing expensive) field survey with expertise from geology and geographic field. Supporting the field action with remote (satellite or aerial) imagine at very high resolution, will reduce the duration of the activity but request an higher financial costs.

We overcome the shortage of money and time with the collection of secondary data already prepared as the 2009 forestall map of FIPI and the 2010 land use map of DONRE. This dataset request an elaboration of the data in order to uniform the spatial information. Especially the land use map request a huge effort. As a matter of fact, the dataset was supplied in its native format, that was Microstaion. Such software is not a GIS but it is a CAD. Therefore, many topological and geometrical aspects were revised and adjusted in order to permit the overlay operation between different dataset.

Finally, the used vector layers (mainly the land use and the forestall maps) had a geographical mismatch with the official communal administrative boundary obtained from the General Statistic Office of Vietnam. Therefore, the hazard maps have some small gaps in the border area, but the hazards grid were shift irregularly from the administrative boundary.

The present work and database development was limited to implement strategies as field work effort or to acquire satellite imagine (or airplane ortho-photo). The effort to measure the frequency of hazard and their impact for the community failed because not all the commune (indeed very few have consistent data) get a comprehensive dataset of hazard frequency and intensity. Therefore, we starting from data at medium scale (DEM with 30 meter of resolutions and climatic data with 1 or 20 km of resolution) and acquiring data from the General Statistic Office General Survey of 2009. This census is carryout with much more precious and detailed then the normal statistic data collected every year. We adding dataset from MONRE (the 2010 land use map) and FIPI (forest map 2009). All this dataset permit as the identify through indicators generally already presented in literature, with the exception of Lao Wind index, that was developed completely new, and was based on the information about this meteorological hazard collected locally and at national level at Hydro-meteorological Service of Vietnam.

The main purpose of this dataset is that allow to conduct comparison among communes and different area of the studied region. Therefore the normalization of the data was conducted in the whole territory and not in each single district or province. Therefore, the value reported in the maps is only a relative index that permit to compare hazard level, vulnerability, adaptive capacity and sensibility across the whole area.

Finally, we can affirm that the activity address the need that every country or part of it has: define a rank of importance of its hazards and risks in the terms of likelihood of their occurrence and the severity of their impacts on the people, infrastructure and ecosystems. As a matter of fact, no country can face all their risks of hazards in the sometime, therefore the reaction measures have to be implemented in parts, with the highest priorities given to the protection of the "hotspots". The maps here presented highlight this hotspot and permit to understand which "component" of the risk is determinant to make a particular area an "hotspots". And thus, will permit to the authority to define a list of priorities of the hazard mitigation actions and risk reduction strategies to be implemented, and furthermore, enhance the efficiency of political decision allowing to focus on the key aspects (for example social adaptive capacity terms rather than institutional adaptive capacity component).

For that reason the decision of the weight of relative importance among adaptive capacity component or among hazards, was left to the local stakeholders and following the AHP methodology for make the decision of stakeholder much more rationale possible.

4.1 Follow up and enhancement

In this section will be highlighted same follow up and actions to undertake to enhance the quality of the results.

4.1.1 Drought

Indicators for the hydrological drought have to be included to give a more realistic drought hazard spatial distribution. The involvement of expert of river hydrology and river modelling will be pivotal. First of all because data on river discharge are essential and this data have to be modelled to represent the river discharge flow. Furthermore, an overview of all situation of water management (irrigation, dyke, etc...) system in the study area is important. The Institute for Water Resources Planning (IWRP), an agency of MARD based in Hanoi, could be a possible partner that addresses all this requirement. This institute is responsible to develop water resources management in Vietnam. The IWRP had already developed the water management plan for the Lao Cai and the Phu Tho provinces (but not for Yen Bai province). However, these plans have little or no consideration of climate change trends, and are dated. A possible suggestion as future cooperation is the development of the water resources plan for the Yen Bai province and the revision of the ones for Lao Cai and Phu Tho provinces including climate change adaptation and risk reduction strategies in relation to drought. Surprisingly, there is not at present international support for developing an integrated plan for the Red river basin. The IWRP is actively looking for international partnership and funds to conduct such work.

4.1.2 Lao Wind

To calculate the hazard level, monthly average of maximum temperature and relative humidity were used. However, The result will be much more precise and adherent to the reality if daily frequency data will be used. The Hydro-meteorological Service of Vietnam own this data but are largely stored in hardcopy format. Need a huge effort of Hydro-meteorological Service to convert such data in digital format to be uploaded in specialized software as ANUSPLIN that can interpolate data until resolution of 1 Km^2 taking in consideration elevation, latitude and longitude value. Moreover to include the effect of topographical morphology on the wind direction a Lagrange model of wind have to be developed starting from the collection of wind speed and direction data in the studied area. Also such data are actually not available in digital format and a strong advise is to support the digitalisation of this data with the cooperation of the Vietnam National Hydro-Meteorological Service.

4.1.3 Soil and geologic map

For landslide hazard but not only, soil map and geological map are very important. However they were not available at a good scale or they are produced with methodologies not consistent in the whole studied area or finally, they didn't cover all the studied area. Such limitation are very important for landslide hazard map, but even for flash flood hazard map, wildfire hazard map and drought hazard map.

4.1.4 Ground validation

The results appear reasonable, but a ground activity may be desirable to validate the hazard distribution maps. However, such kind of ground verification trips are very time and money consuming activities. However, is to discuss the validity of the results with the local experts from districts and collecting their comment and suggestion to enhance the reliability of the maps in a future refinement of the present results.

4.1.5 Participatory hazard mapping

The team strongly recommend to implement the involvement of commune and village staff in the future to elaborate hazard map in participatory way aimed to collect the local knowledge. Such information may be implement and enhance the result of the physical hazard map produced in our present work. The participatory hazard mapping methodologies suggest and partially experimented is descript in the following bullet point list:

- Held meeting with the representatives of the communes Rural Development and Land Administration office. They have to illustrate the hazardous situation in their own area and identify the hazardous area on the topographic map.
- Reported locations of hazard will be visited and checked via GPS. The data were then combined with prior knowledge of risk factors from the scientific literature and from the local participants to produce a mapping of likely risk areas for future hazards.
- With the local participants, conduct an “analytical hierarchy process” approach, which got them to compare each risk factor in turn to all others, and rank them by priority weight.

4.2 What the risk mapping process highlighted

The risk mapping process highlighted that local experiences of coping and mitigating disaster originate in the community itself. Local people and local authorities have always understood their surrounding vulnerabilities and risks, and have therefore always had disaster coping mechanisms at local levels, commune and village levels. They know what are the important indicators for the risk and vulnerability assessment. However, this local knowledge has rarely been recorded in traditional risk maps. This participatory GIS risk mapping successfully transferred unrecorded local knowledge into maps through the process of indicator development and weighting. The process of developing risk maps also mobilized the participation of the local authorities and technical departments at district and provincial levels and succeeded in establishing trust, respect and an exchange of information among local authorities as well as local planners. This involvement assisted in the development of the climate change adaptation and disaster risk reduction plans. The assessment and mapping thus showed that, when mobilized, local technical staff can become actively involved in the decision-making process and recommend solutions for risk reduction. As a result, the risk maps and recommended actions are suited to the local situation. Standard disaster management plans are no longer issued in a top-down way; instead, each commune develops its own specific plans. The study provided a potential alternative for local governments to consider as they develop disaster management plans: currently in Viet Nam most disaster risk reduction plans are prepared by leaders without their community’s participation, and consequently may not take community needs and interests into account, and may be unfeasible to implement.

The participatory approach in this risk mapping ensures local authority will use the maps for their planning because it fits their interests. Through the process, dialogues in which opinions are exchanged and needs and wishes clarified in order to achieve a common understanding of the situation and the obstacles involved is essential for overcoming the communication gap between stakeholders. The consultative meetings in three provinces at which the potential risks are discussed and mapped provide local technical staff with the skills they need to identify and analyze their surrounding risks and to come up with new ideas regarding disaster risk management.

The risk maps highlighted that although the physical vulnerability and exposure factors are important to determine the loss and damage caused by a disaster, other factors such as socio-economic vulnerability have greater impact on economic loss and damage. It is clear that a mix of actions are needed to reduce disaster risk problems that combine structural spatial measures (access/reduced proximity to river, havens) with structural measures (building or retrofitting houses for safety) and social measures (reducing poverty in particular as a root contributor to vulnerability). Bearing in mind that relocation of families is not often a viable option for many reasons—proximity to the place of work being a prime one—the hazard mapping provides useful data indicating action that should be taken to reduce vulnerability in specific locations. Hazard mapping and planning for disaster prevention must therefore highlight how to address disaster risk in a comprehensive manner with strategies dealing simultaneously with social, economic, spatial and structural issues.

Finally, the risk maps provide a quick illustration of areas that are at risk. GIS technology, the thematic map can show selective information such as infrastructure indicators, social capital indicators etc.

4.3 Partnership to overcome GIS operational problems

GIS mapping requires sophisticated and expensive software and hardware, as well as extensive workload to input, retrieve and analyze data. This can lead to incomplete databases if the workload is underestimated. Collecting data from the field and then entering it into the computer is time-consuming and costly. These technical problems could be solved by partnerships with local technical department such as DONRE as the have the GIS information center for data collection and technical support, since the human resources as well as the software and hardware are available in the center. Such partnerships also create opportunities technical staff to enhance their practical skills and gradually increase disaster awareness.

Another issue is that of access to reliable data. Since GIS is a relatively new technique in Viet Nam, the spatial data is scarce and inconsistent. Significant time is required to collect data from the field as well as to process and geo-reference the secondary data. To overcome this problem strong support is needed from national and provincial GIS projects using the same coordination system, to provide access to the GIS database for disaster risk management purposes. It is also essential to have a clear understanding of what data needs to be collected before implementing data collection since this stage takes up the most time and money. The stakeholders must, therefore, first clarify the community risk management goals and objectives and then determine what data is needed in order to accomplish them.

Finally, databases for GIS mapping need to be updated regularly. Thus, the data collection should be the responsibility of local department at DARD or DONRE. The technical staff should be trained to collect and input data. Data processing and analysis should be carried out at district level, where databases can be retrieved from communes. The role of provincial government is to support the network that retrieves this data and delivers it to the Provincial Committee for Flood and Storm Control, so that a disaster management plan can be developed in a timely and effective manner.

4.4 Conclusion

The vulnerability assessment and mapping found that the integration of local knowledge into the process of mapping provided important factual data and ideas about the social and physical environment, while identifying vulnerabilities to disasters and developing disaster management strategies. This project proved that these contributions can be incorporated into other, often science-based, activities and methodologies associated with present-day programs and policies for disaster risk management. As part of this integration, new technology and capacities derived from GIS and remote sensing must quickly become an essential element in community-based disaster management projects and in the application of the findings from these projects.

Using local knowledge in disaster management also enables local communities to participate actively in the decision-making process. Local knowledge is a powerful resource and therefore a key element in disaster risk reduction. Integrating local knowledge into disaster risk management can improve the quality of disaster management plans by providing policy makers and practitioners with deeper insight into the many different aspects of disaster vulnerabilities and the interrelated role of local peoples and their cultures.

Finally, this mapping could be replicated in other areas or contexts provided that several conditions are met. The first important condition is that the local authorities accept the approach, and recognize that the map-making process is as important as the resulting maps. Second, relevant technical and human resources must be available as this model requires certain technical skills to use GIS software.

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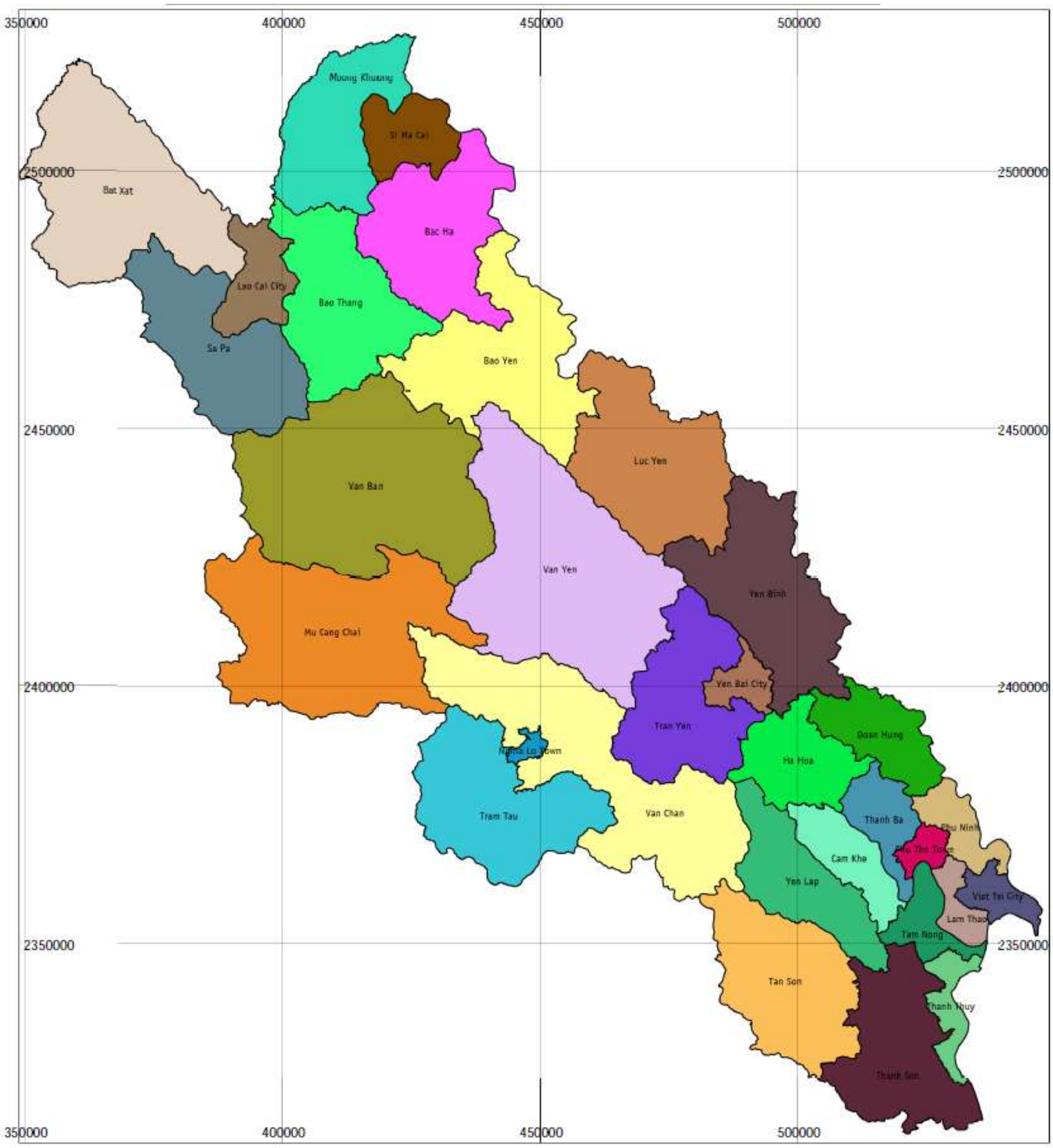
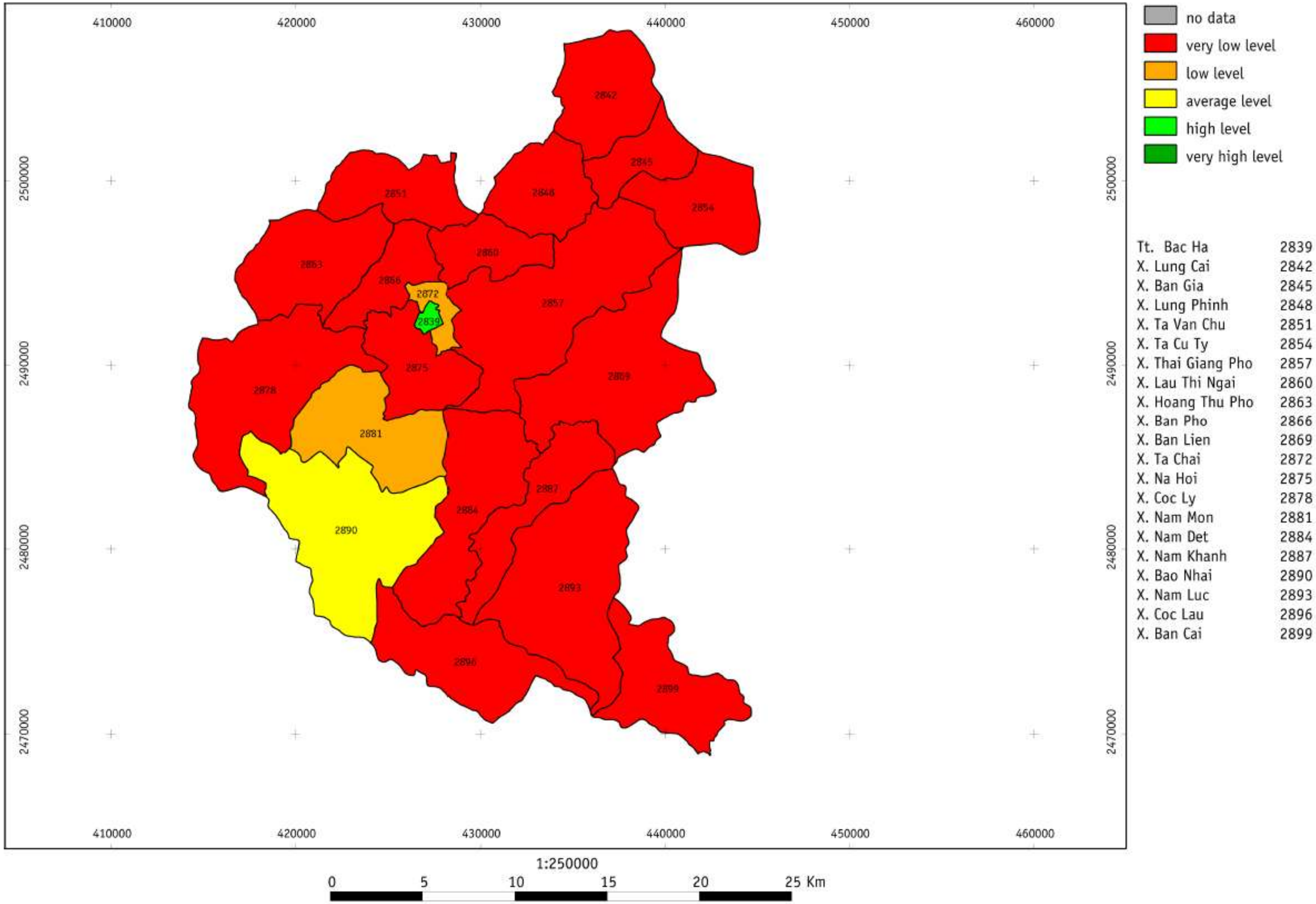
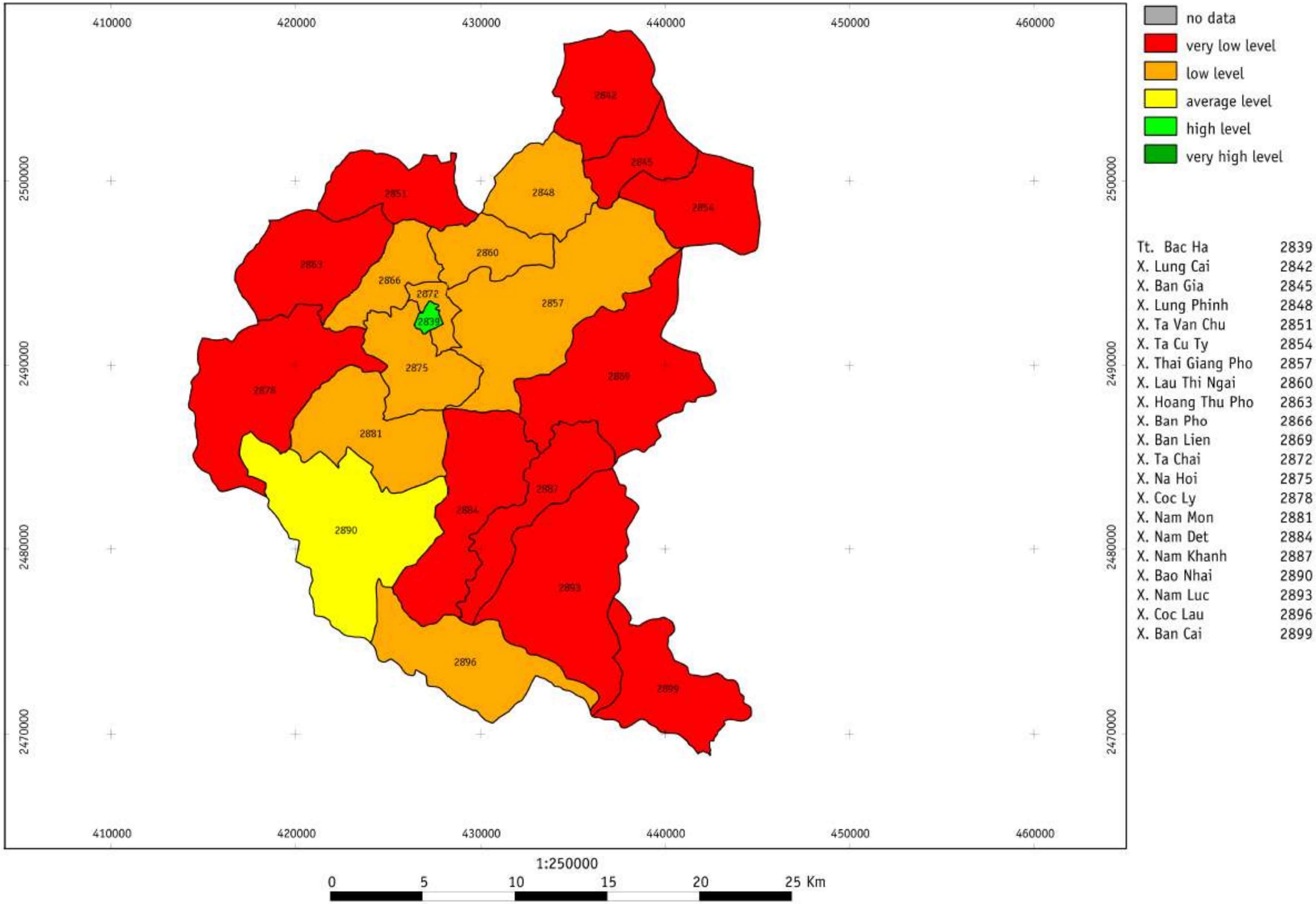
Study Area: The districts



Lao Cai - Bac Ha Adaptive Capacity – Institutional Component



Lao Cai - Bac Ha Adaptive Capacity – Infrastructural Component



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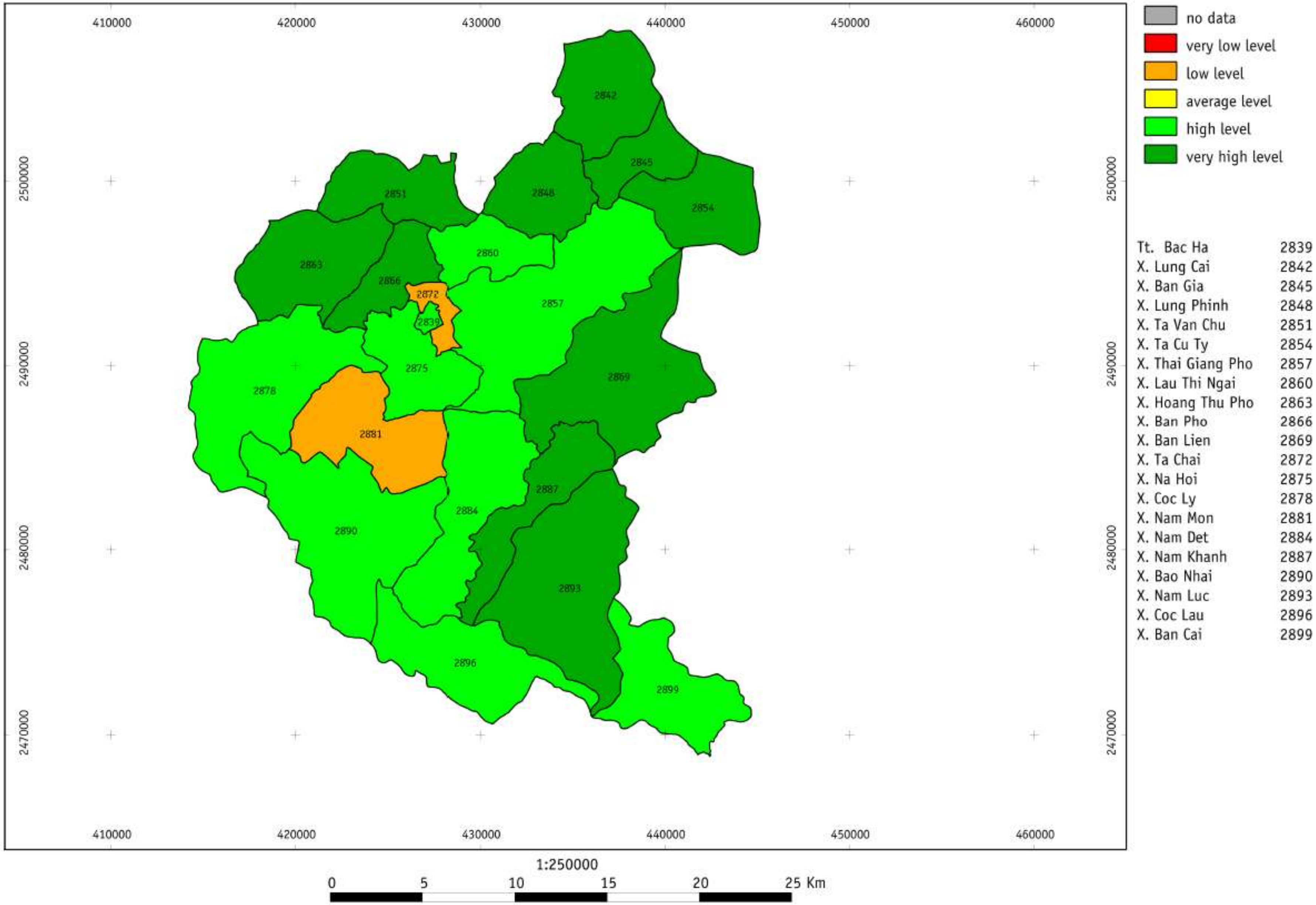
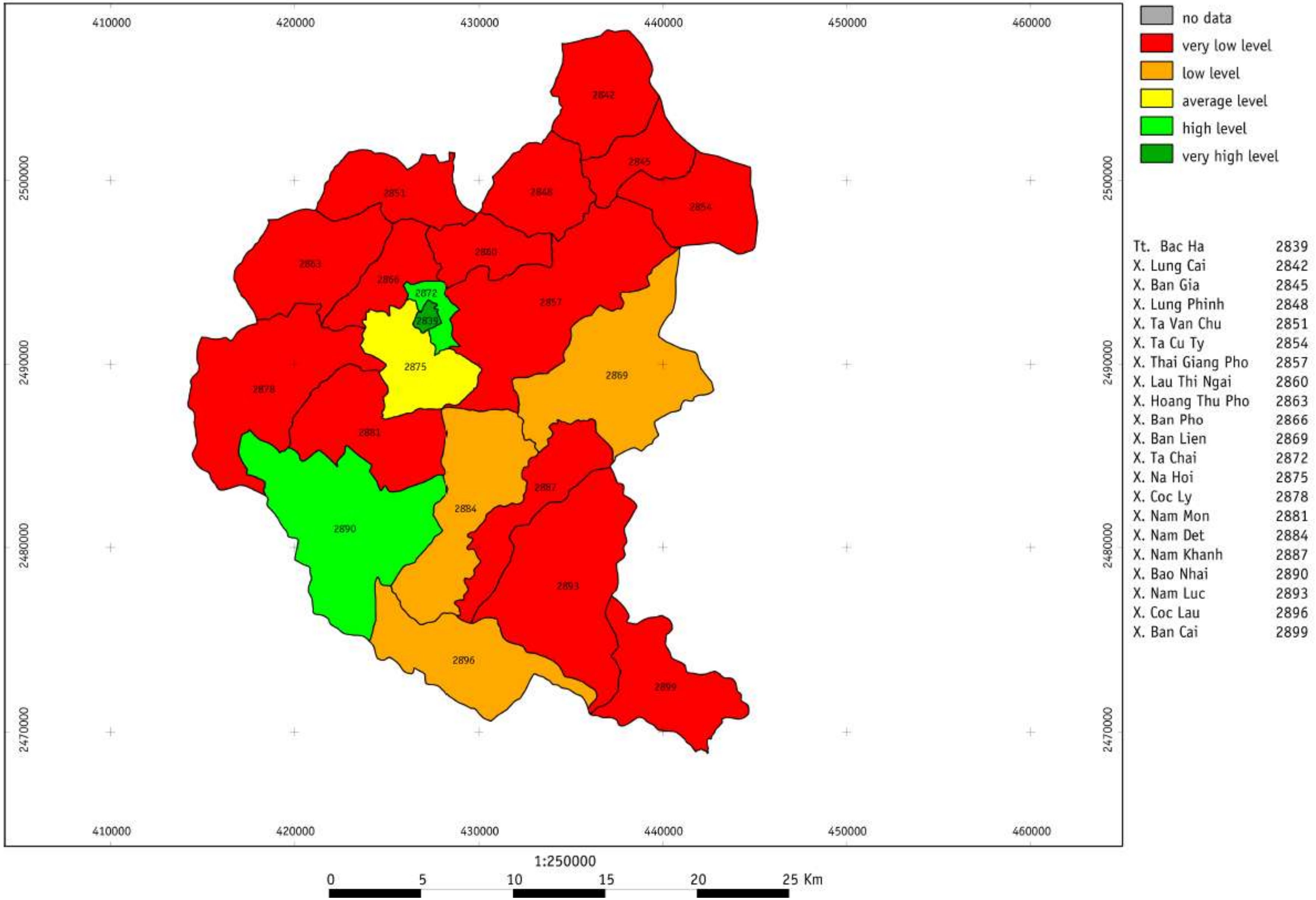
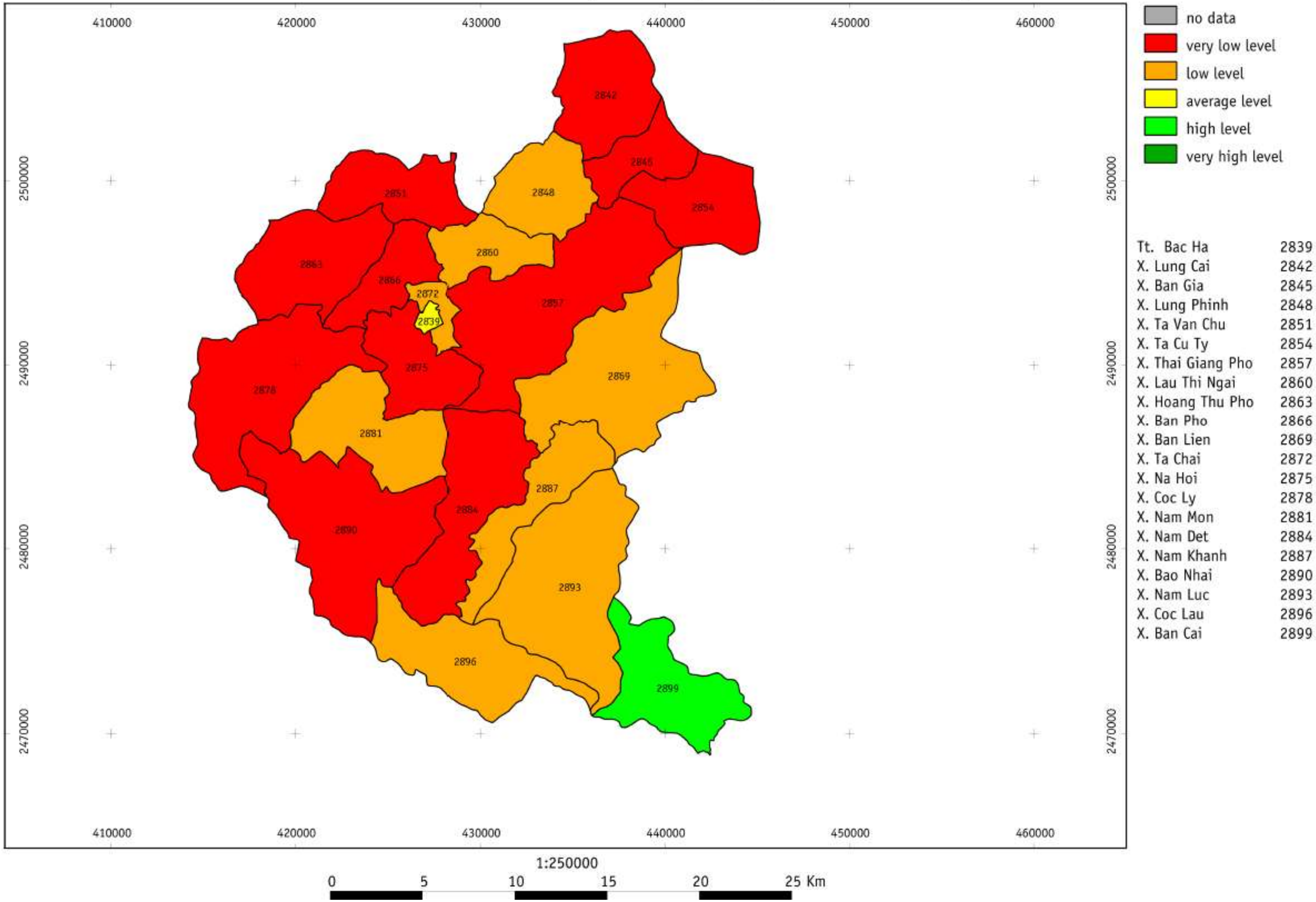


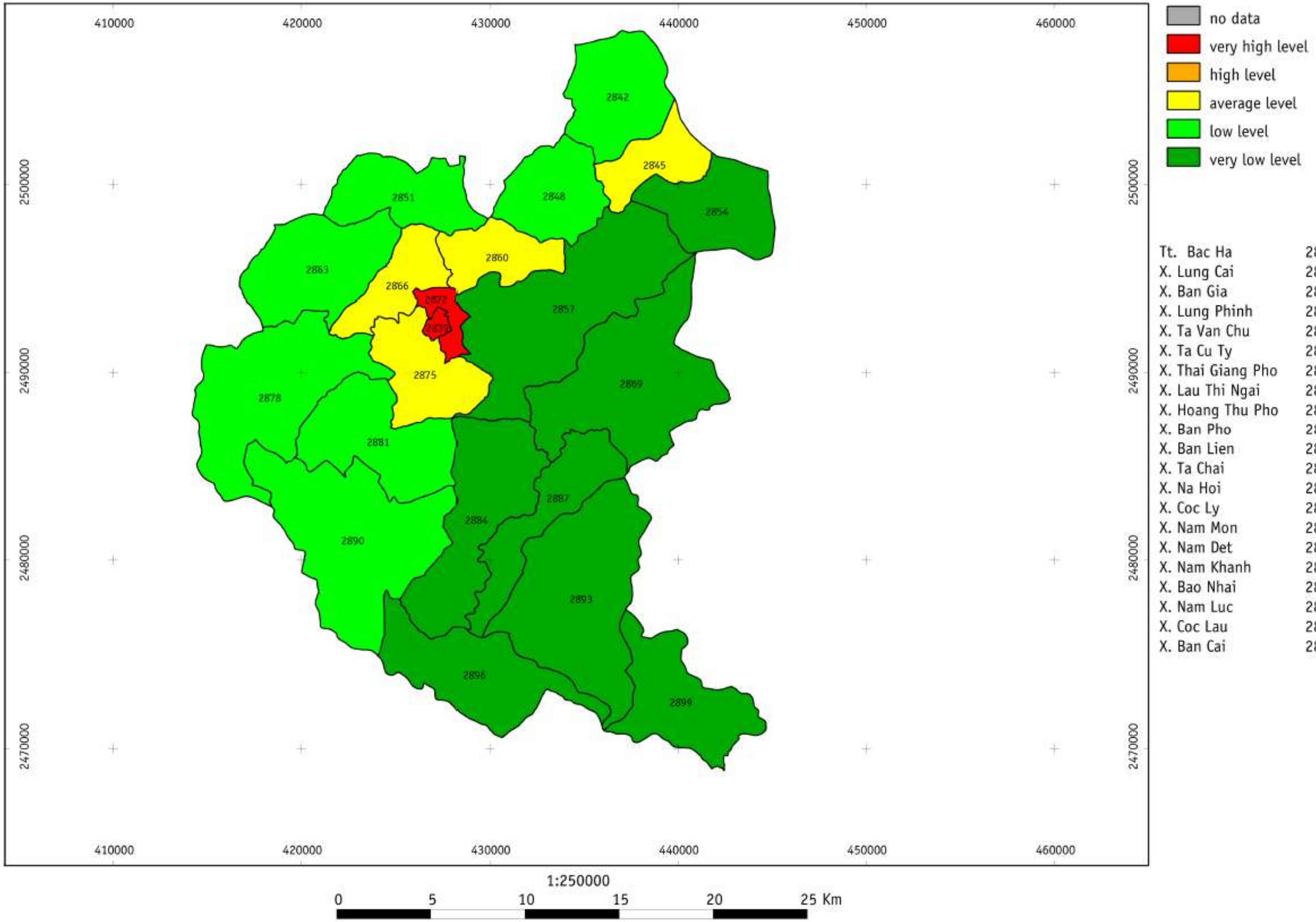
Lao Cai - Bac Ha Adaptive Capacity – Social Component



Lao Cai - Bac Ha Adaptive Capacity – Natural Component



Lao Cai - Bac Ha – Sensitivity



Tt. Bac Ha	2839
X. Lung Cai	2842
X. Ban Gia	2845
X. Lung Phinh	2848
X. Ta Van Chu	2851
X. Ta Cu Ty	2854
X. Thai Giang Pho	2857
X. Lau Thi Ngai	2860
X. Hoang Thu Pho	2863
X. Ban Pho	2866
X. Ban Lien	2869
X. Ta Chai	2872
X. Na Hoi	2875
X. Coc Ly	2878
X. Nam Mon	2881
X. Nam Det	2884
X. Nam Khanh	2887
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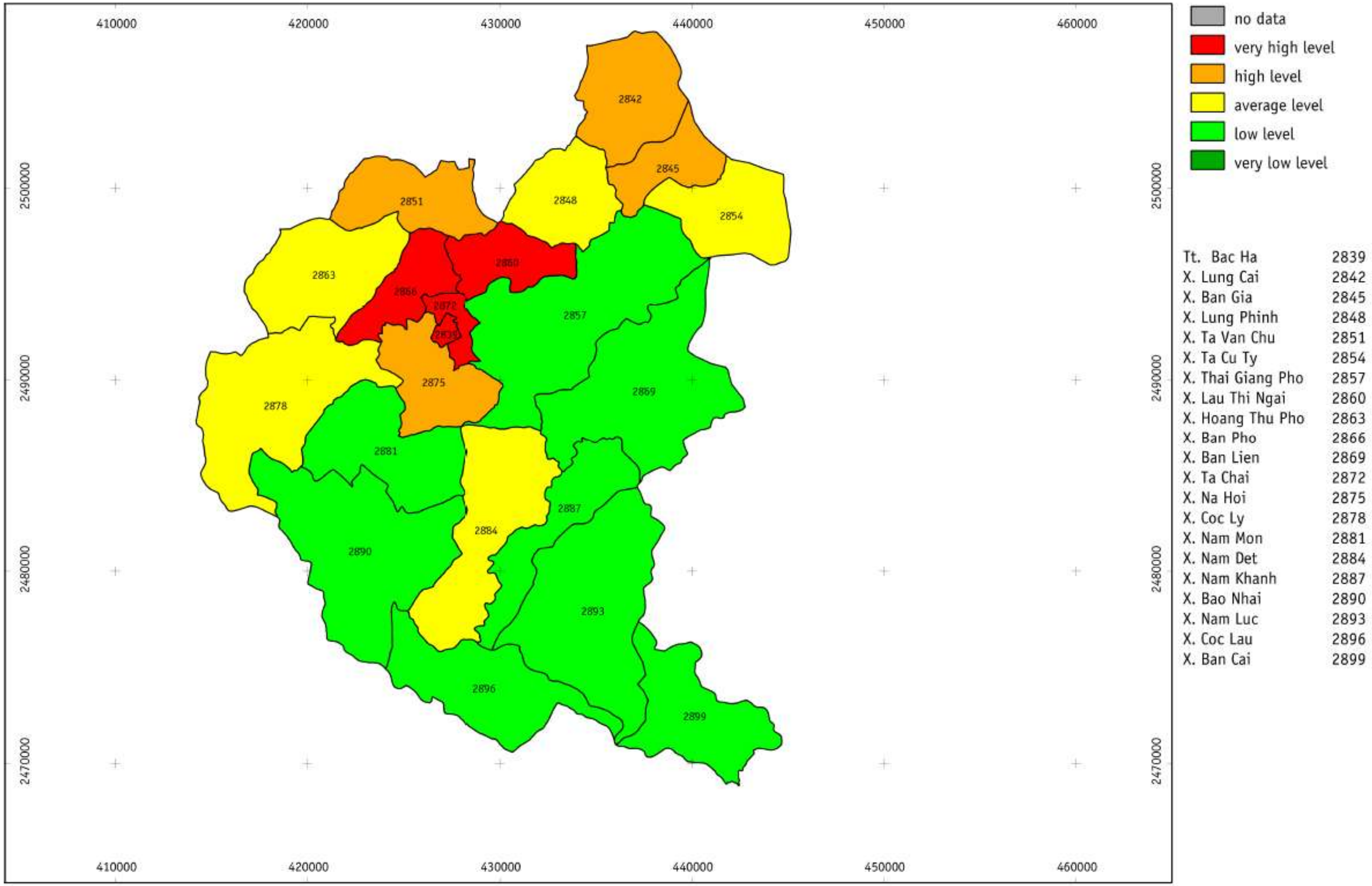
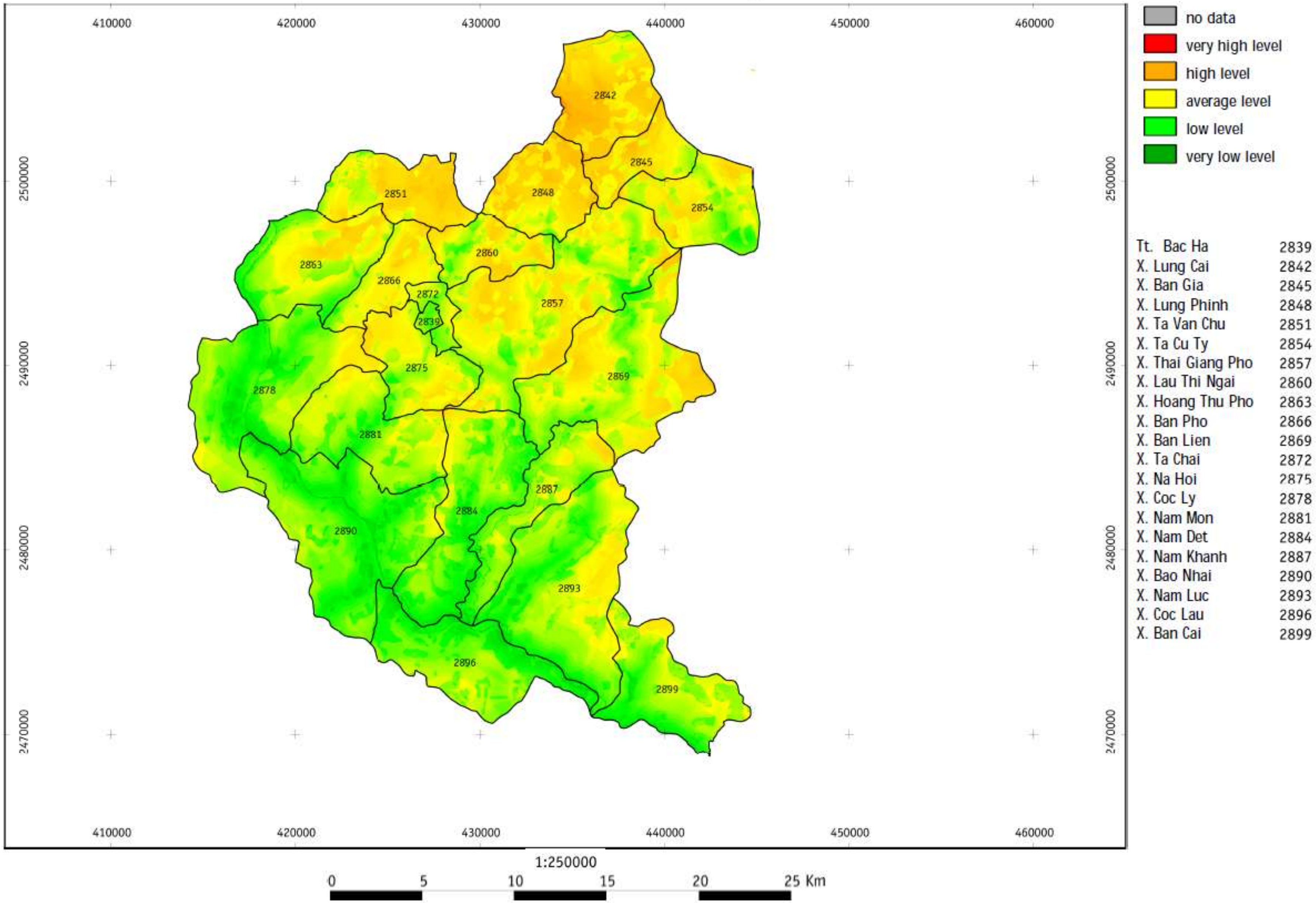
X. Ban Cai	2899

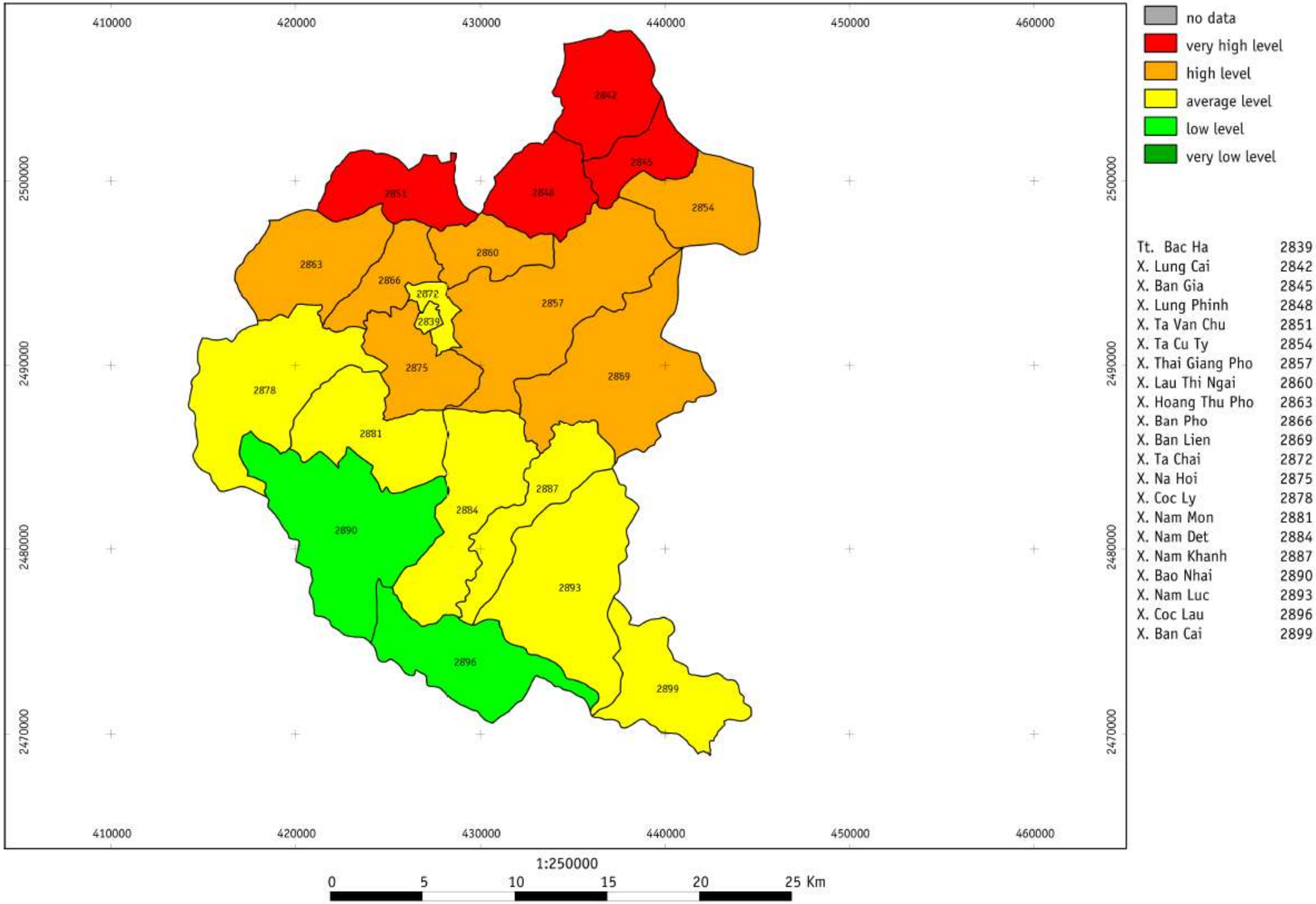
Lao Cai - Bac Ha – Vulnerability



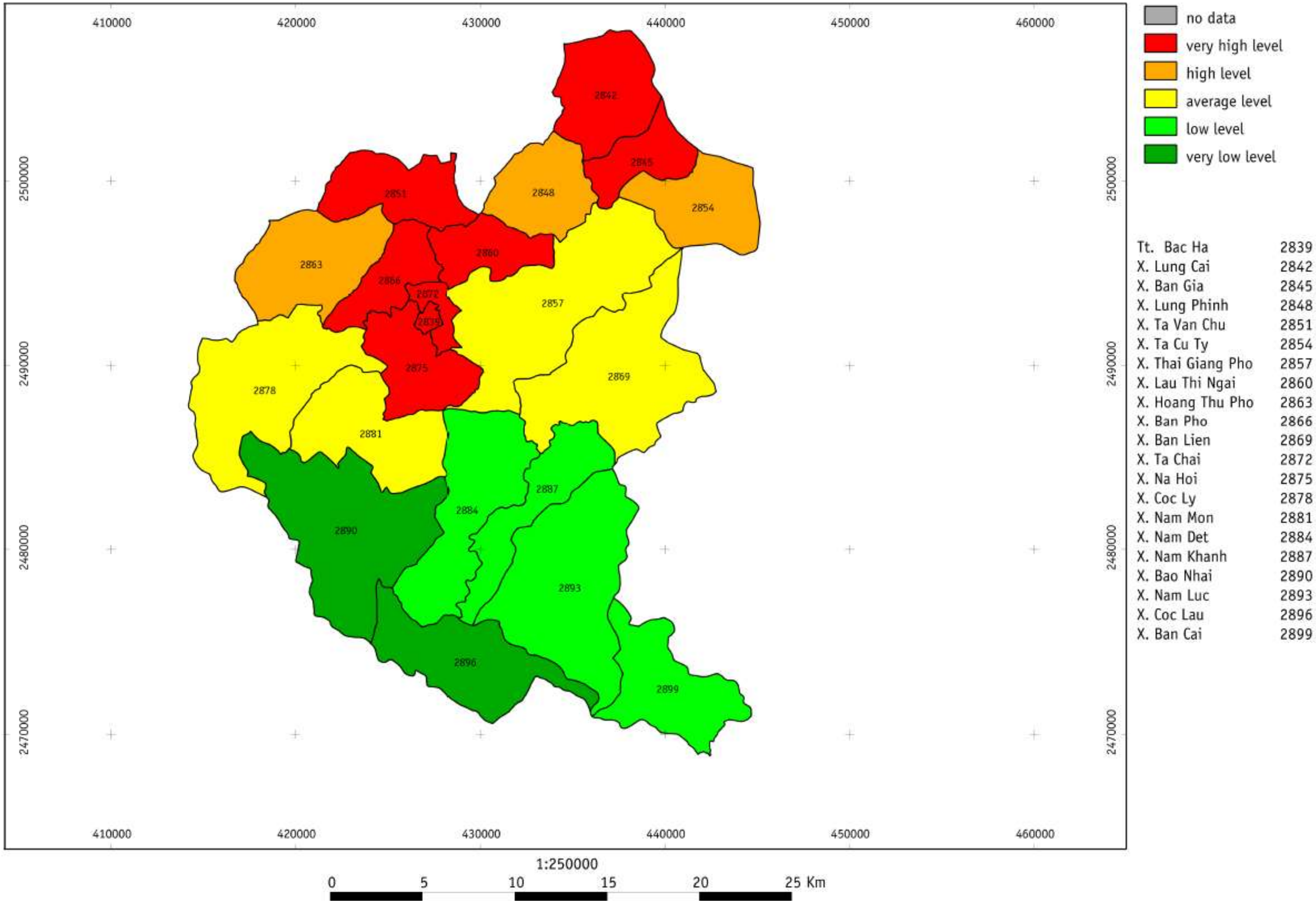
Lao Cai - Bac Ha – Drought's hazard



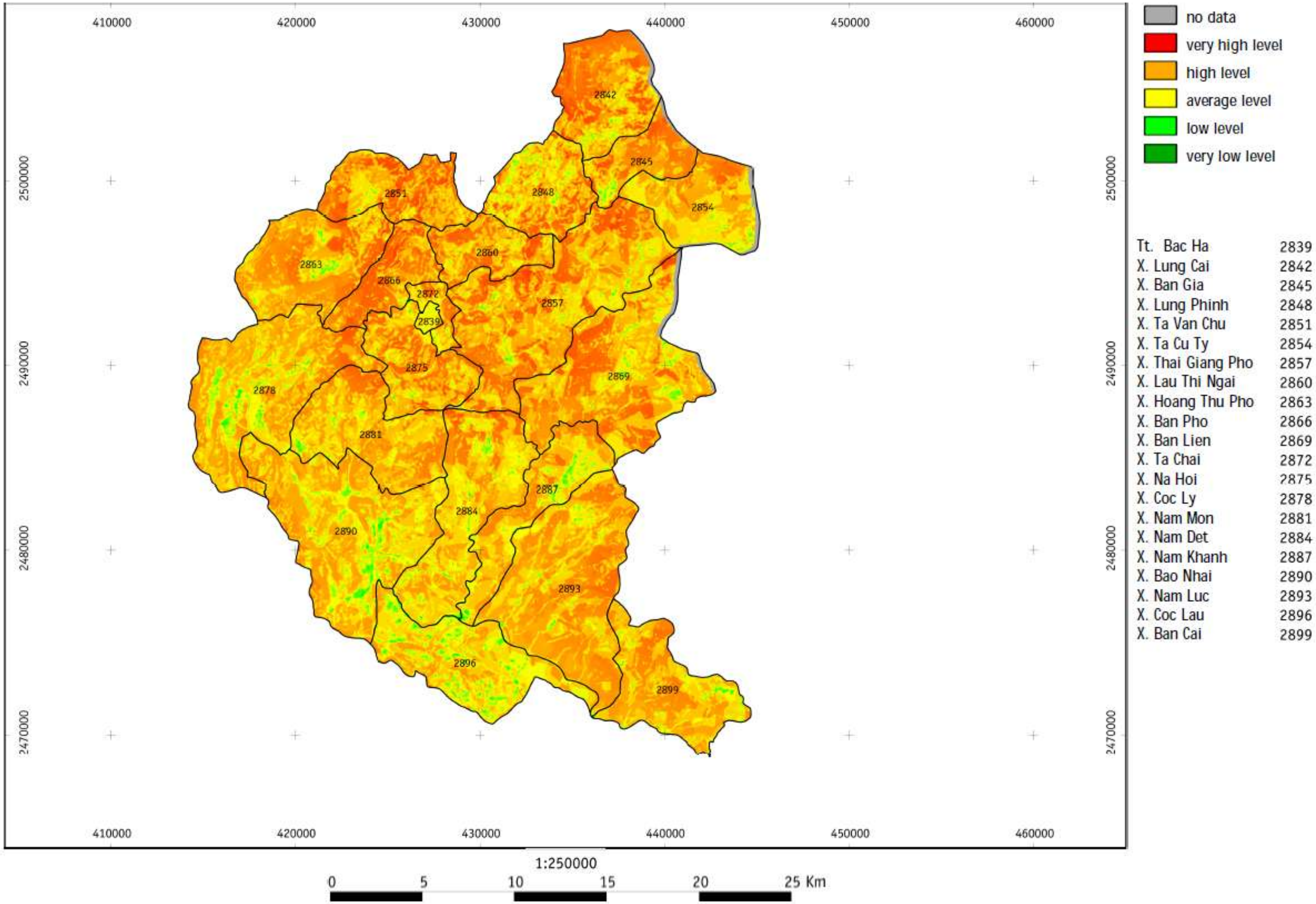
Lao Cai - Bac Ha – Drought's hazard average



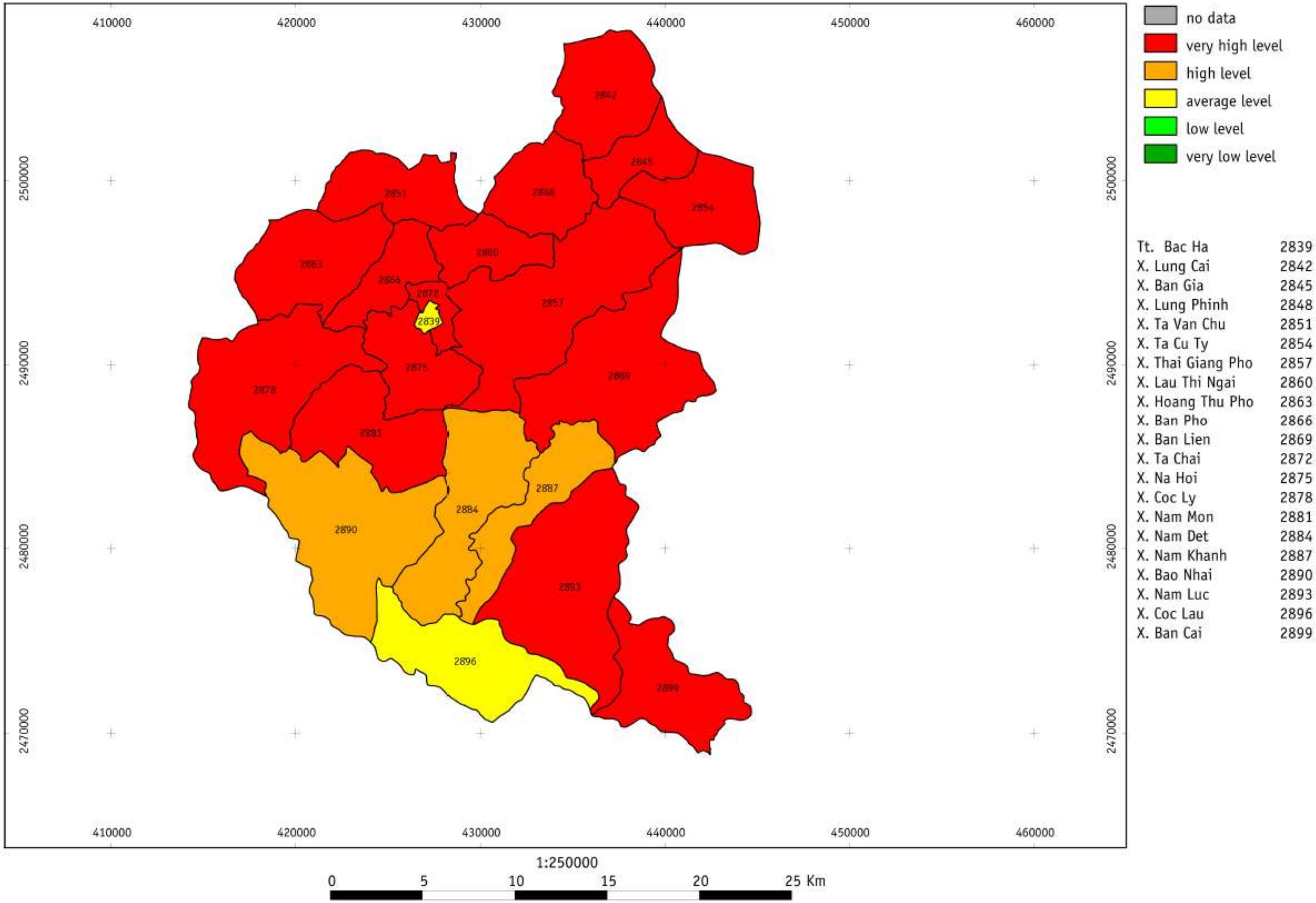
Lao Cai - Bac Ha – Drought's risk



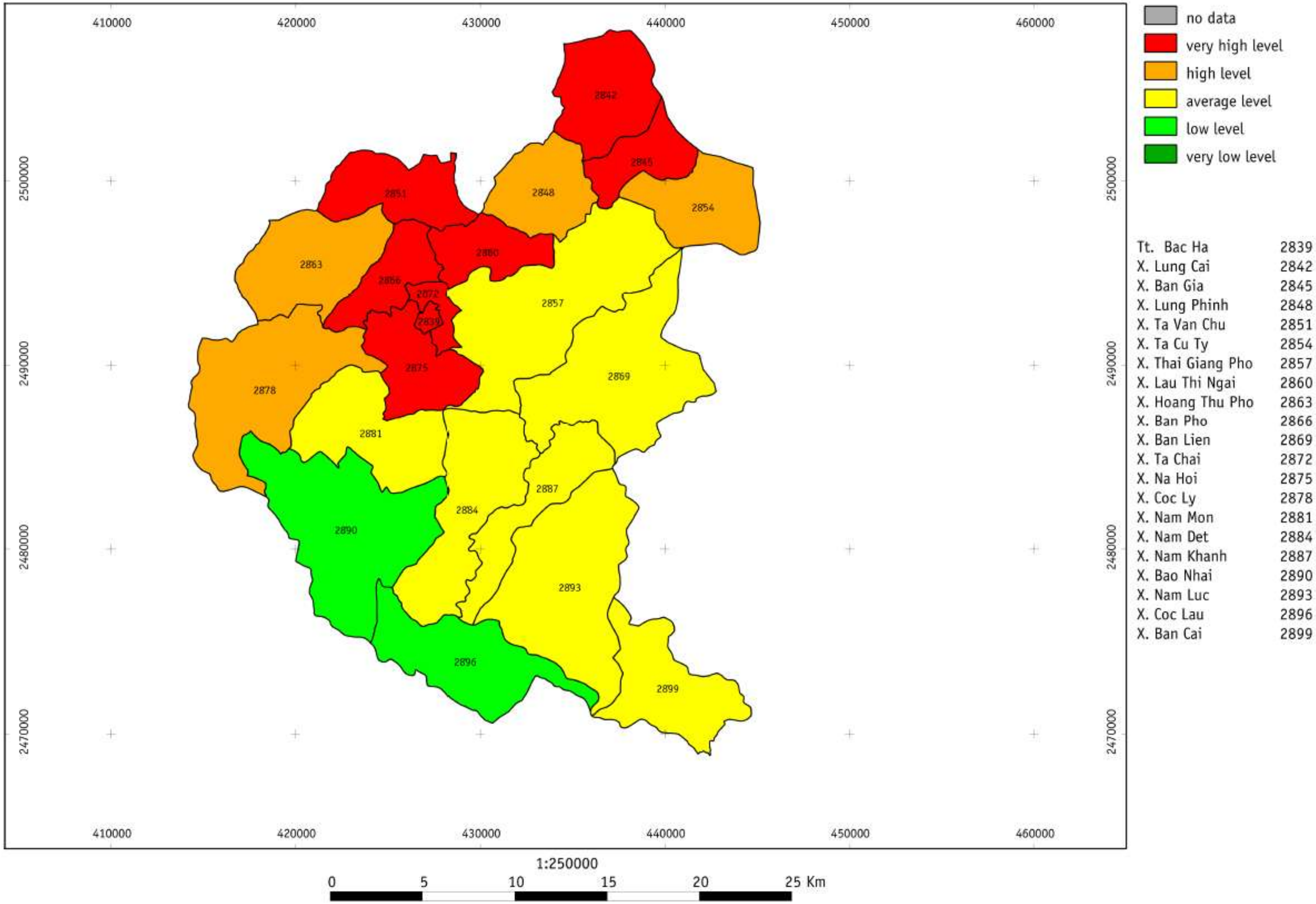
Lao Cai - Bac Ha – Flash Flood's hazard



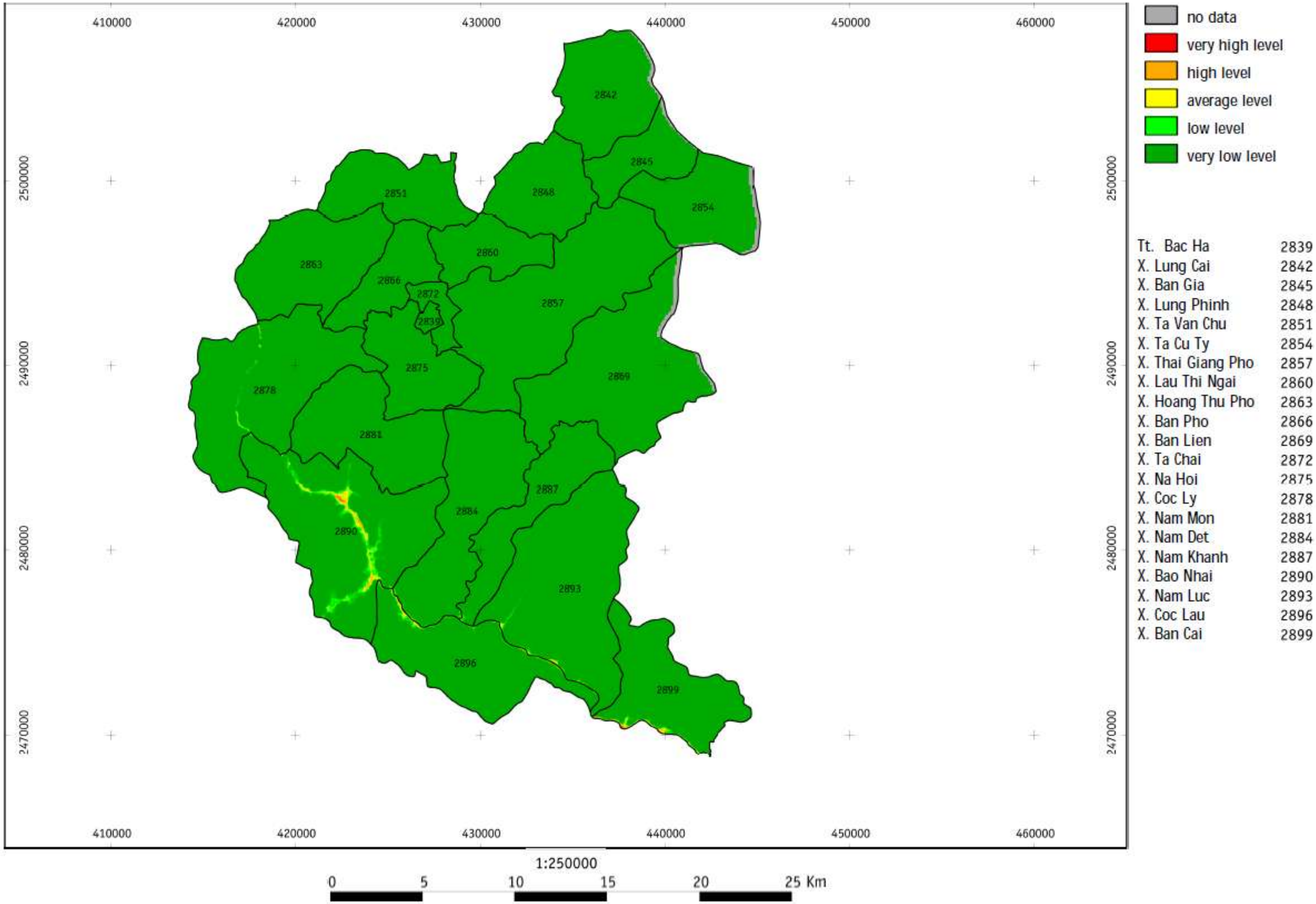
Lao Cai - Bac Ha – Flash Flood's hazard average



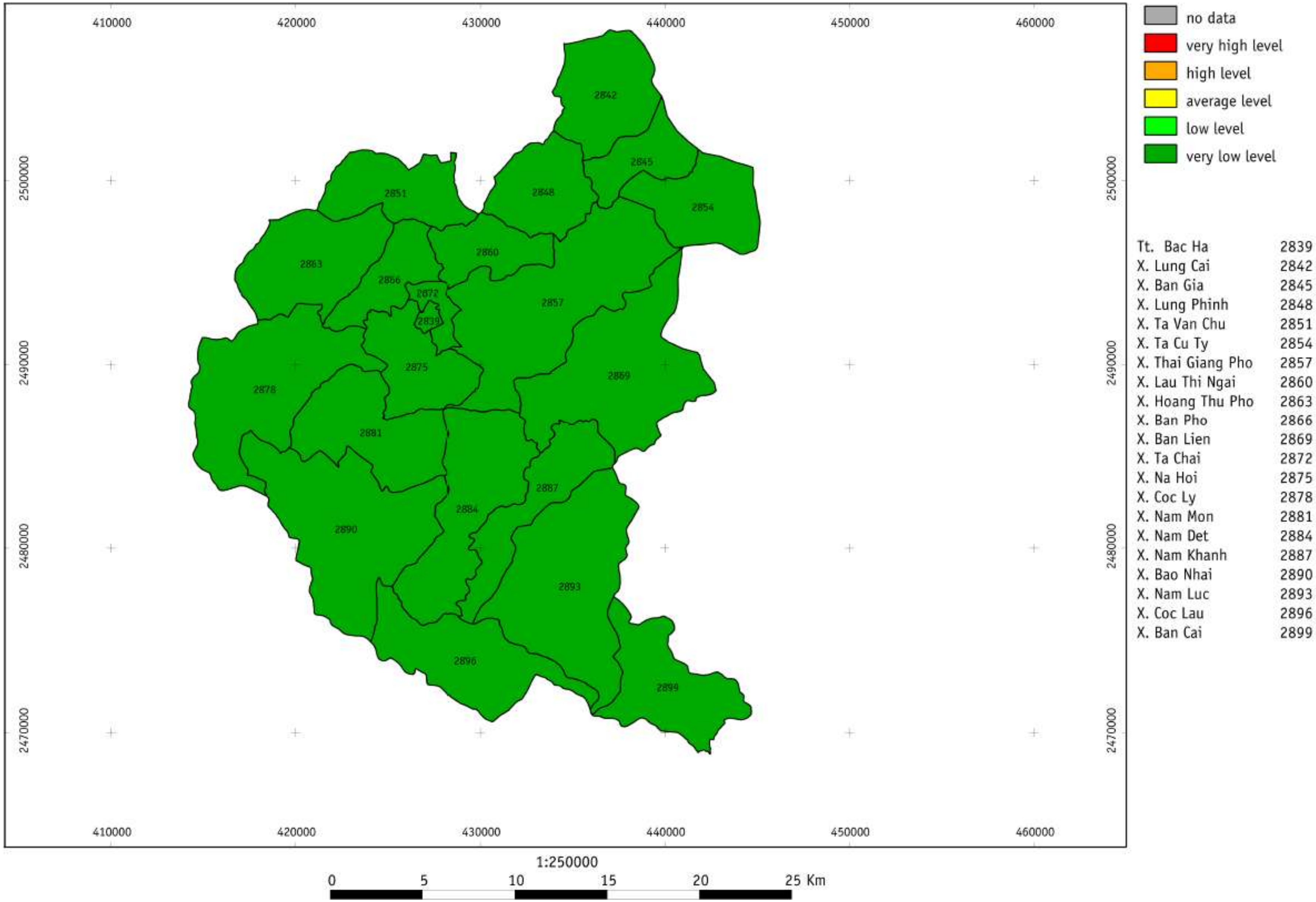
Lao Cai - Bac Ha – Flash Flood's risk



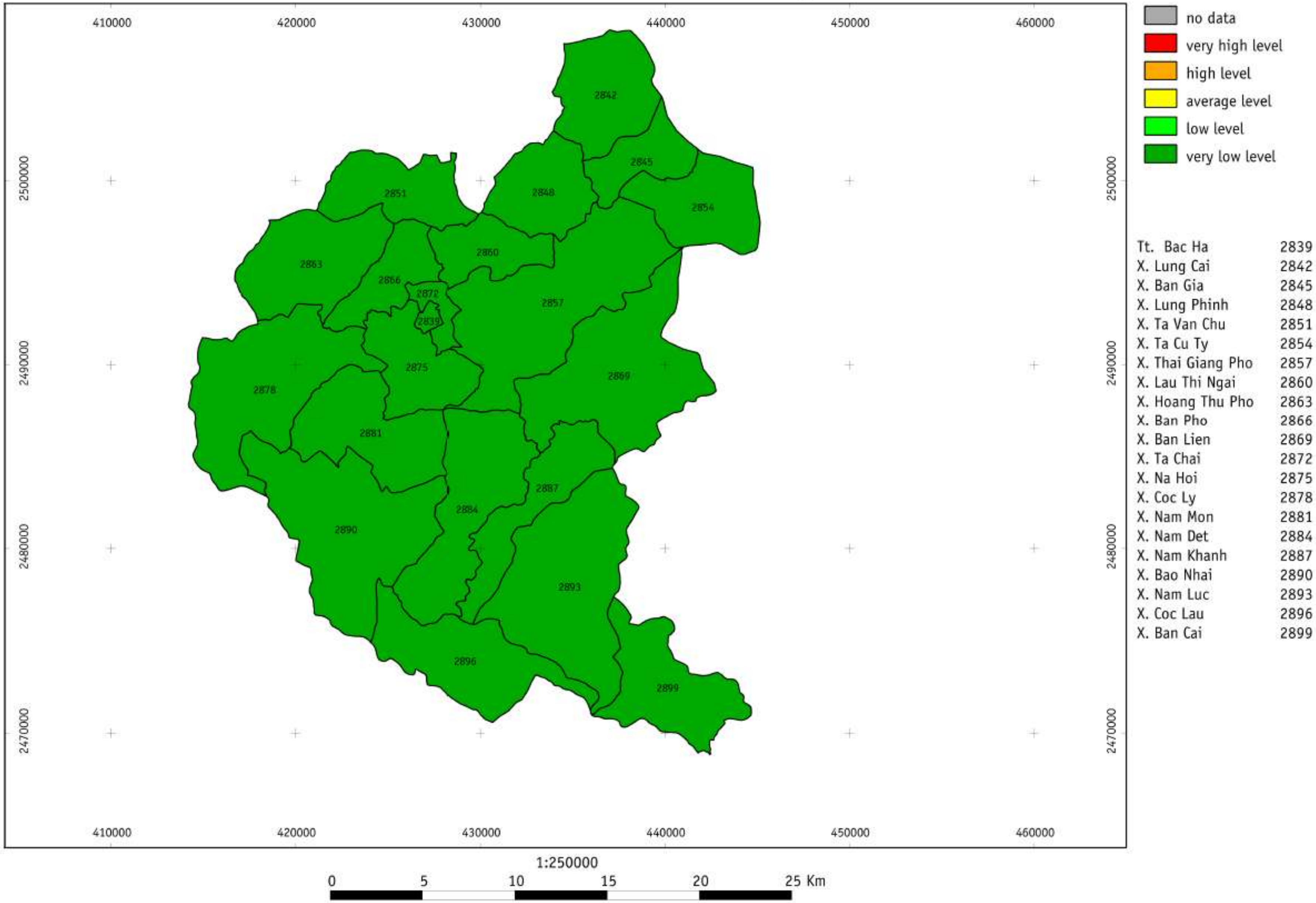
Lao Cai - Bac Ha –Flooding's hazard



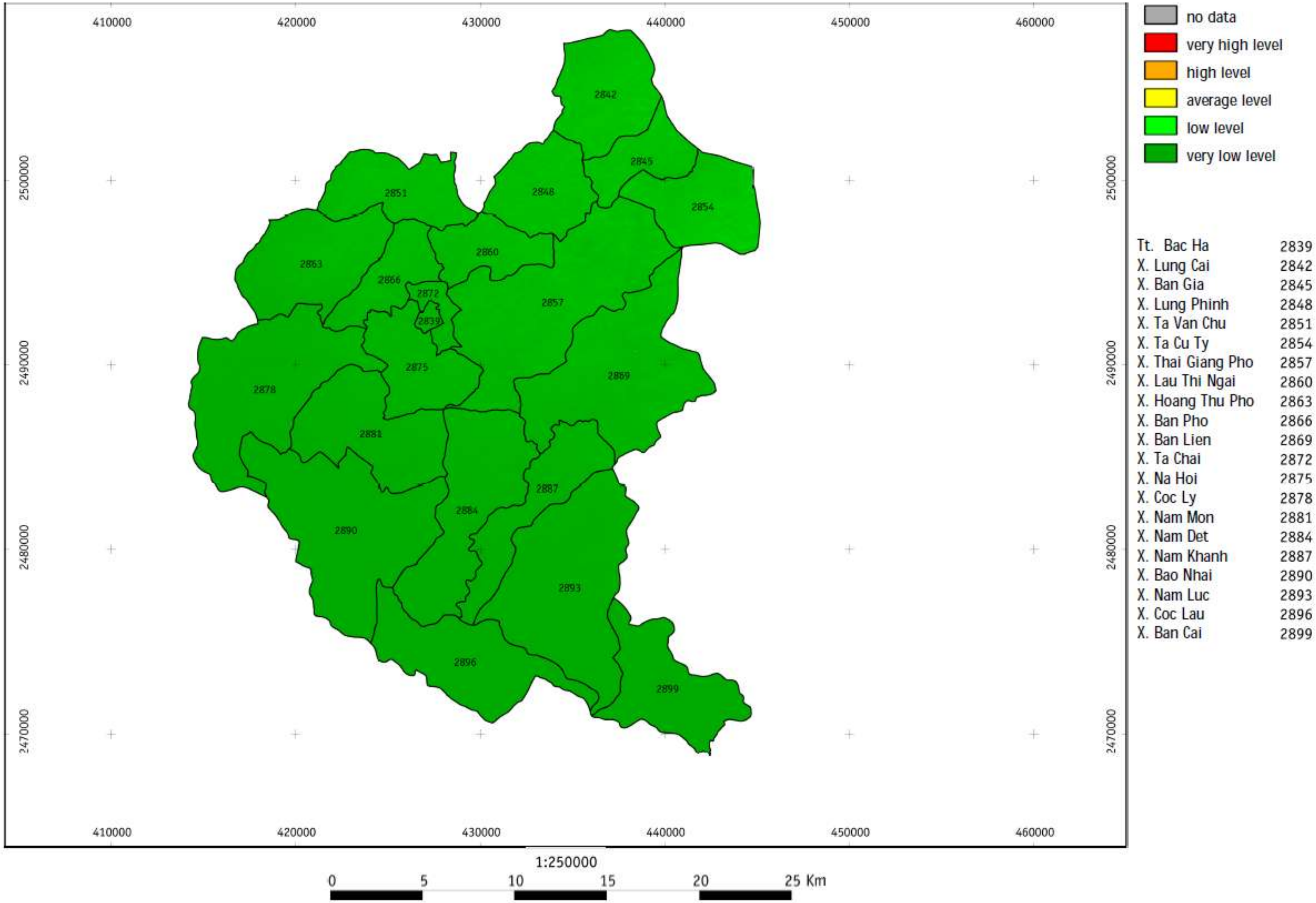
Lao Cai - Bac Ha –Flooding's hazard average



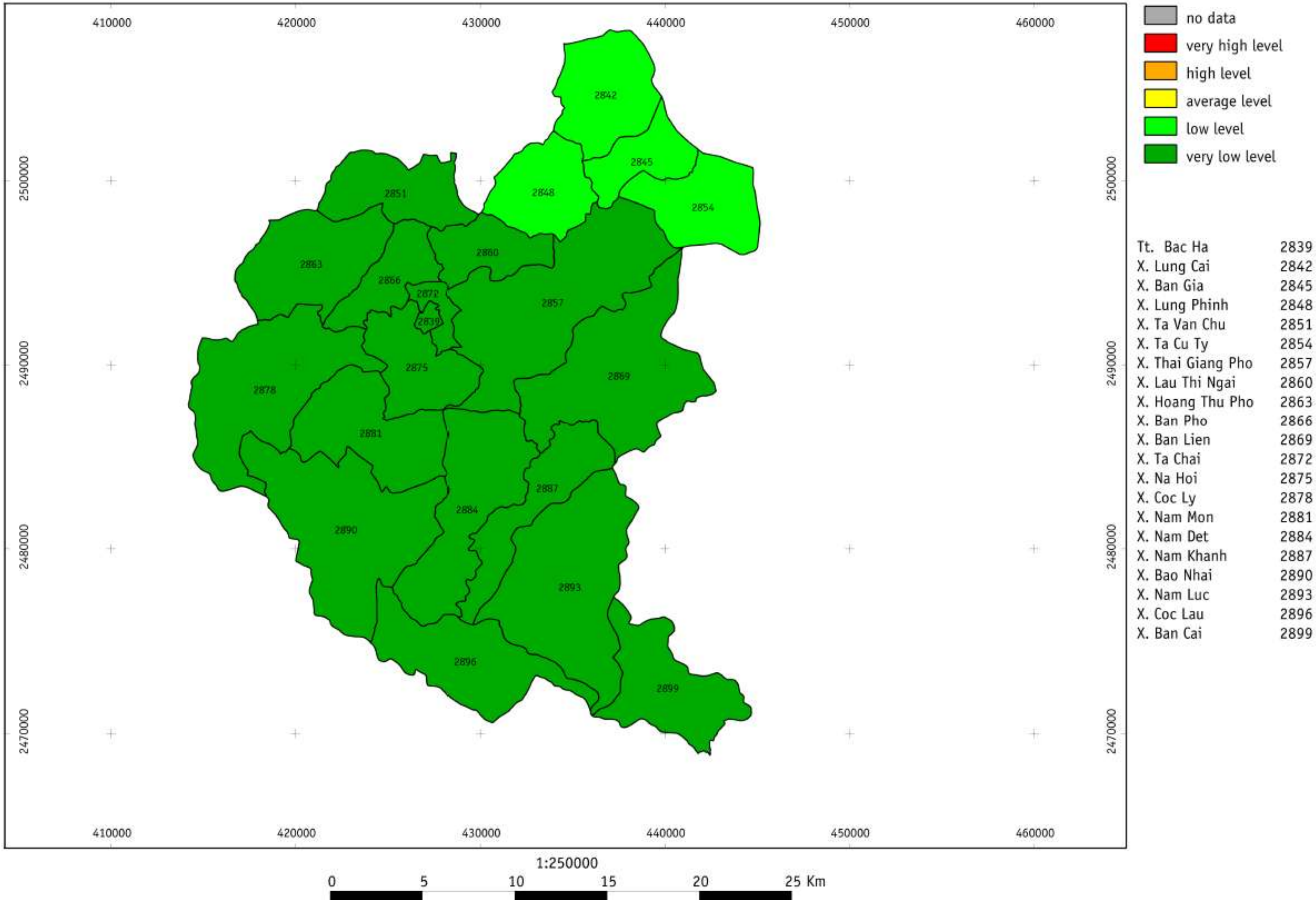
Lao Cai - Bac Ha –Flooding's risk



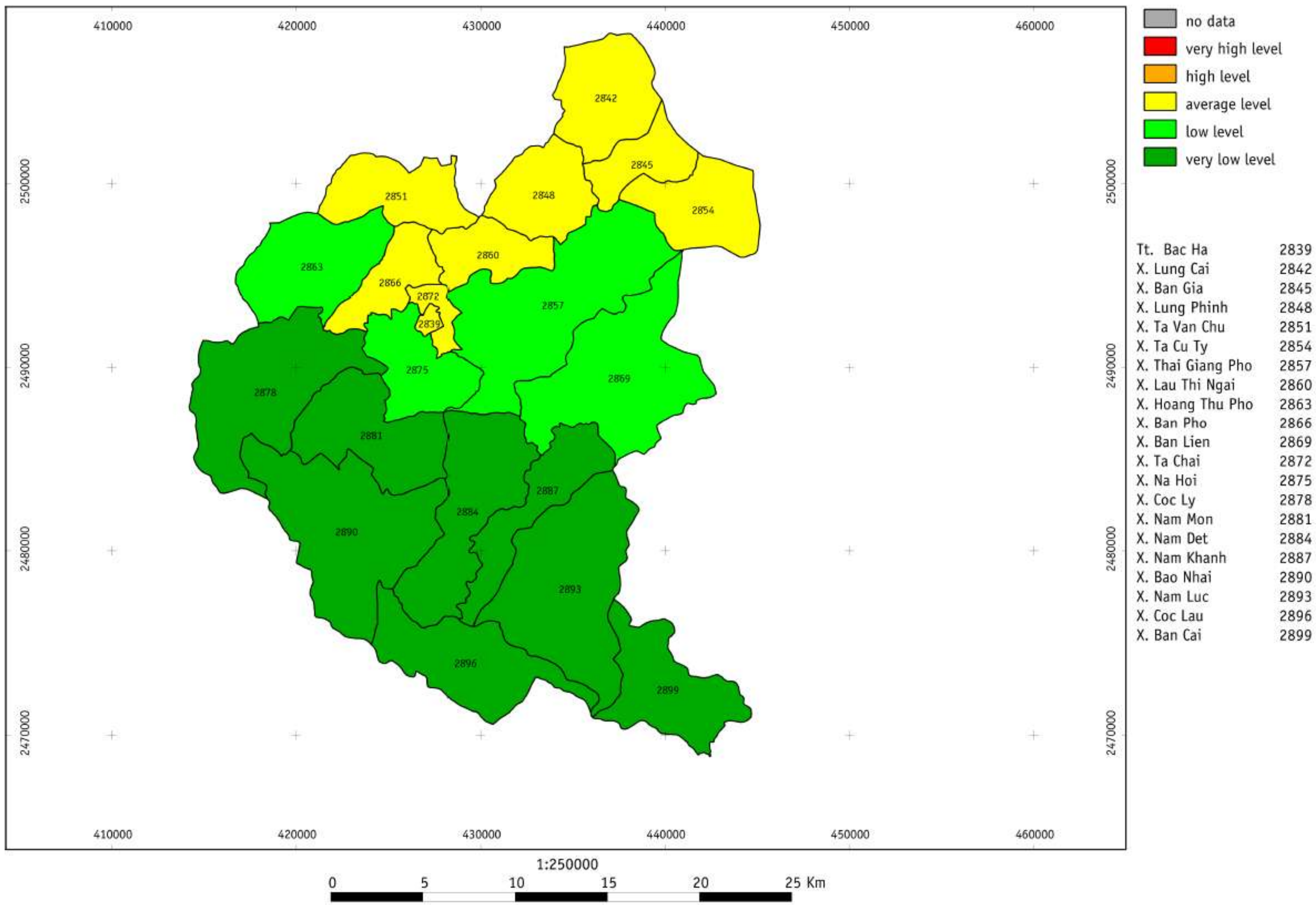
Lao Cai - Bac Ha –Frost' s hazard



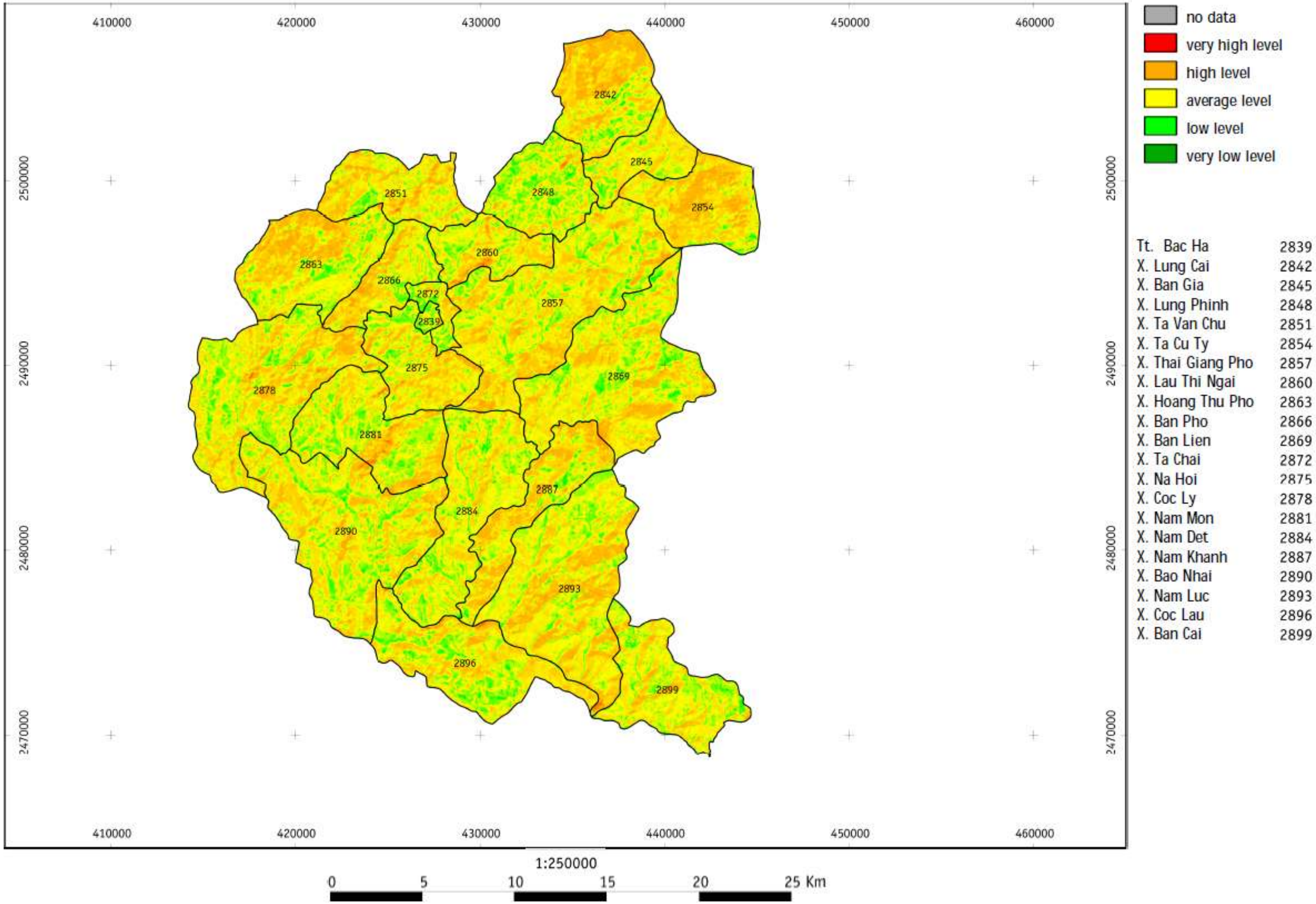
Lao Cai - Bac Ha –Frost' s hazard average



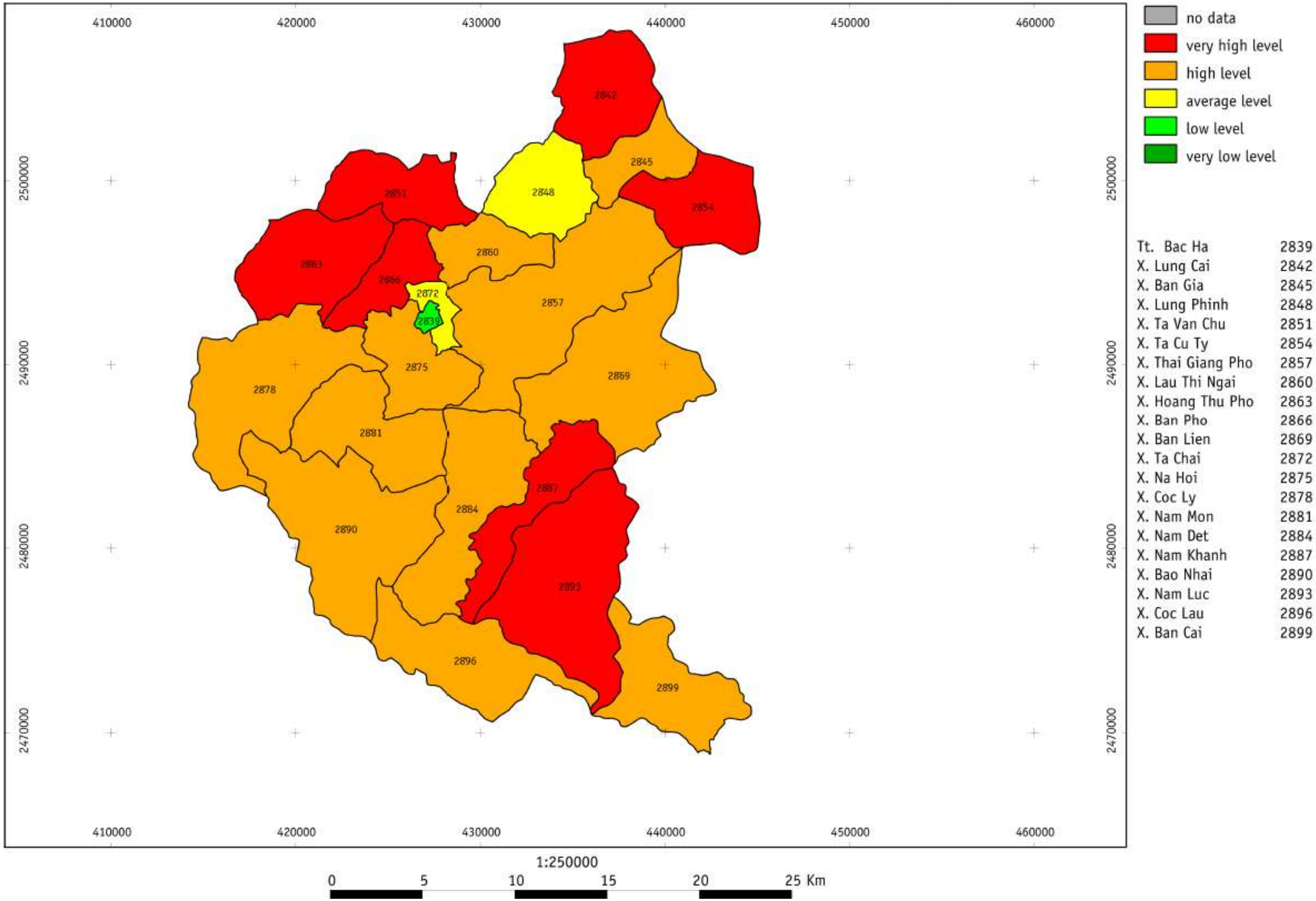
Lao Cai - Bac Ha –Frost' s risk



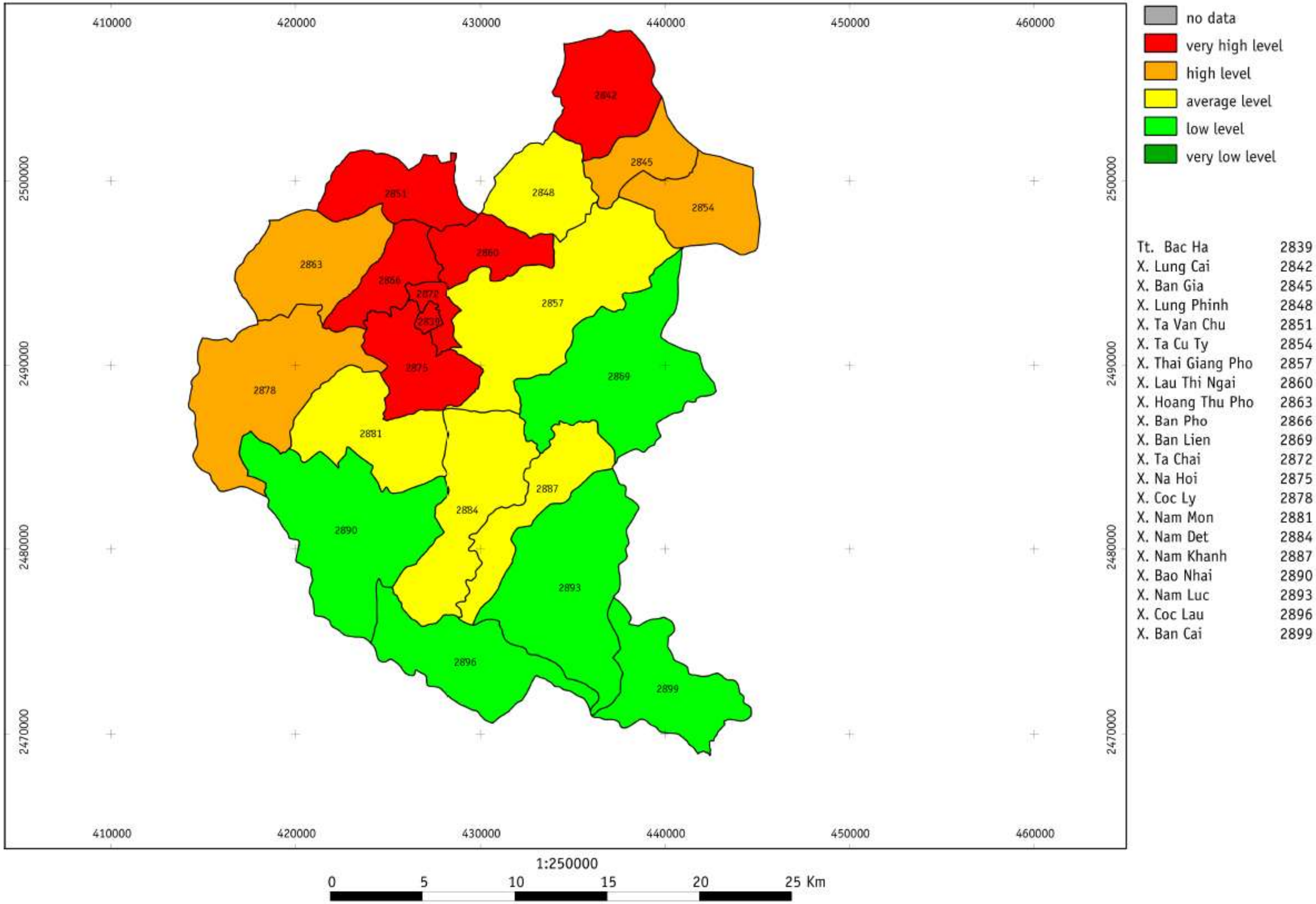
Lao Cai - Bac Ha –Landslide' s hazard



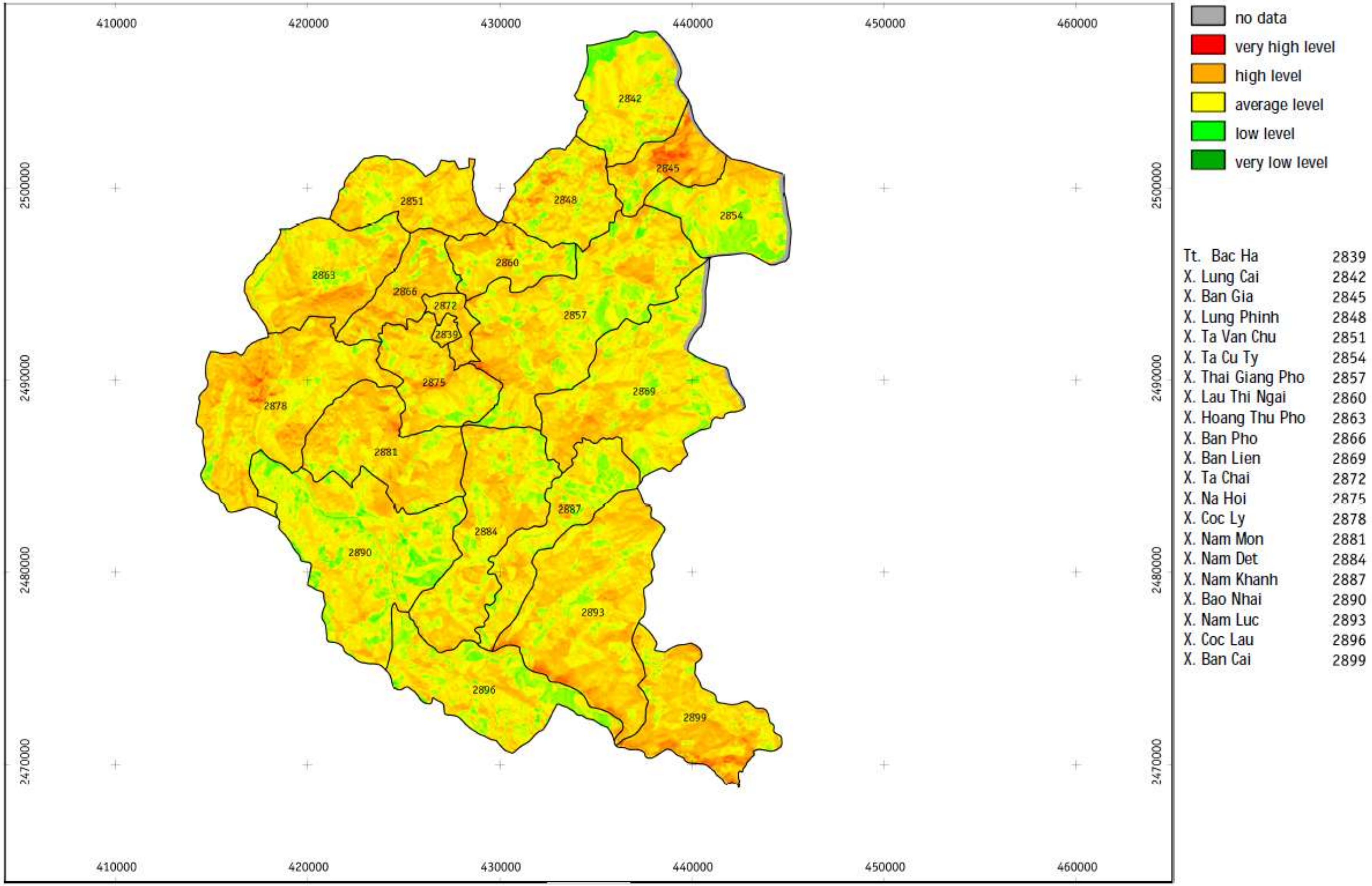
Lao Cai - Bac Ha –Landslide' s hazard average



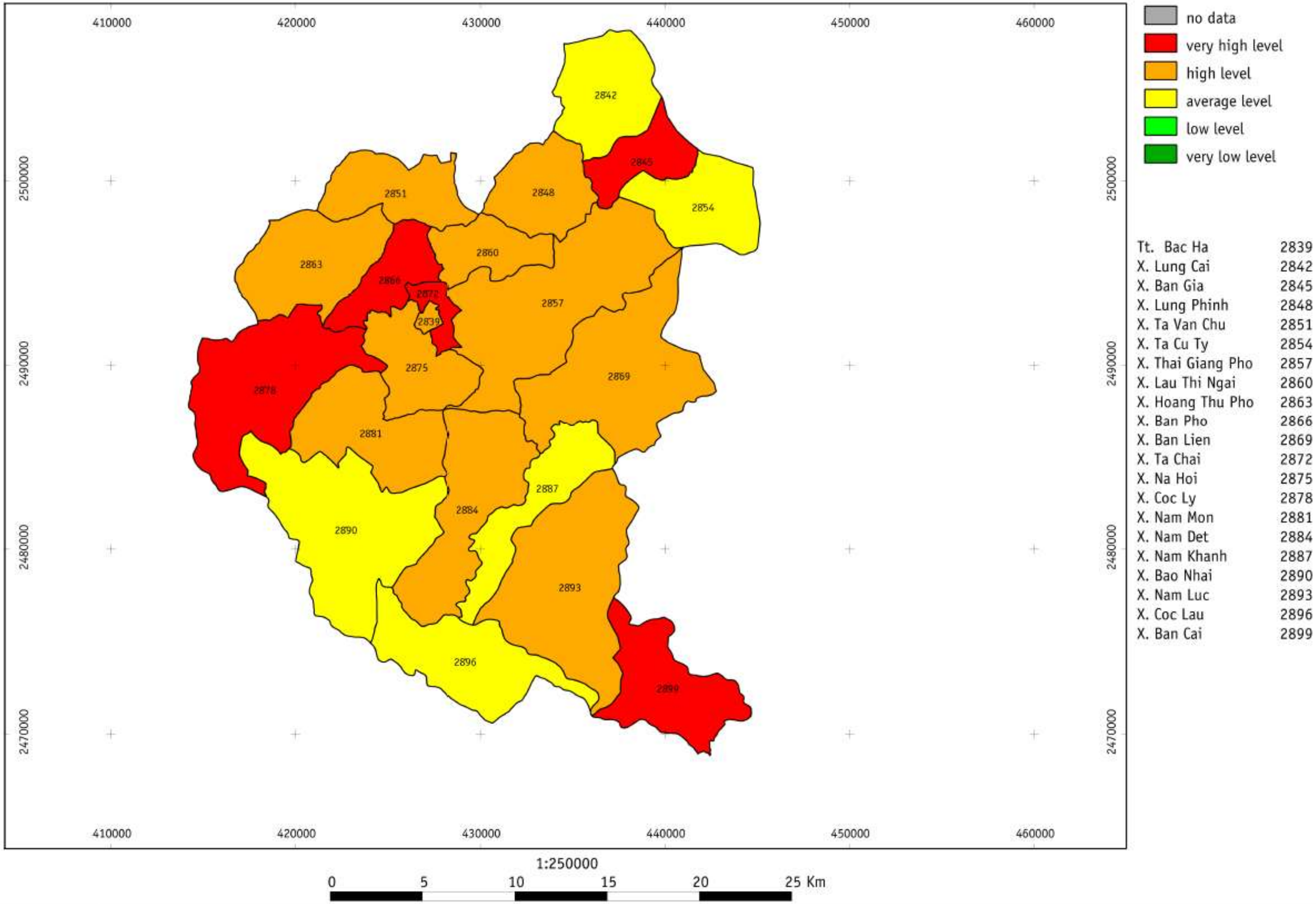
Lao Cai - Bac Ha –Landslide' s risk



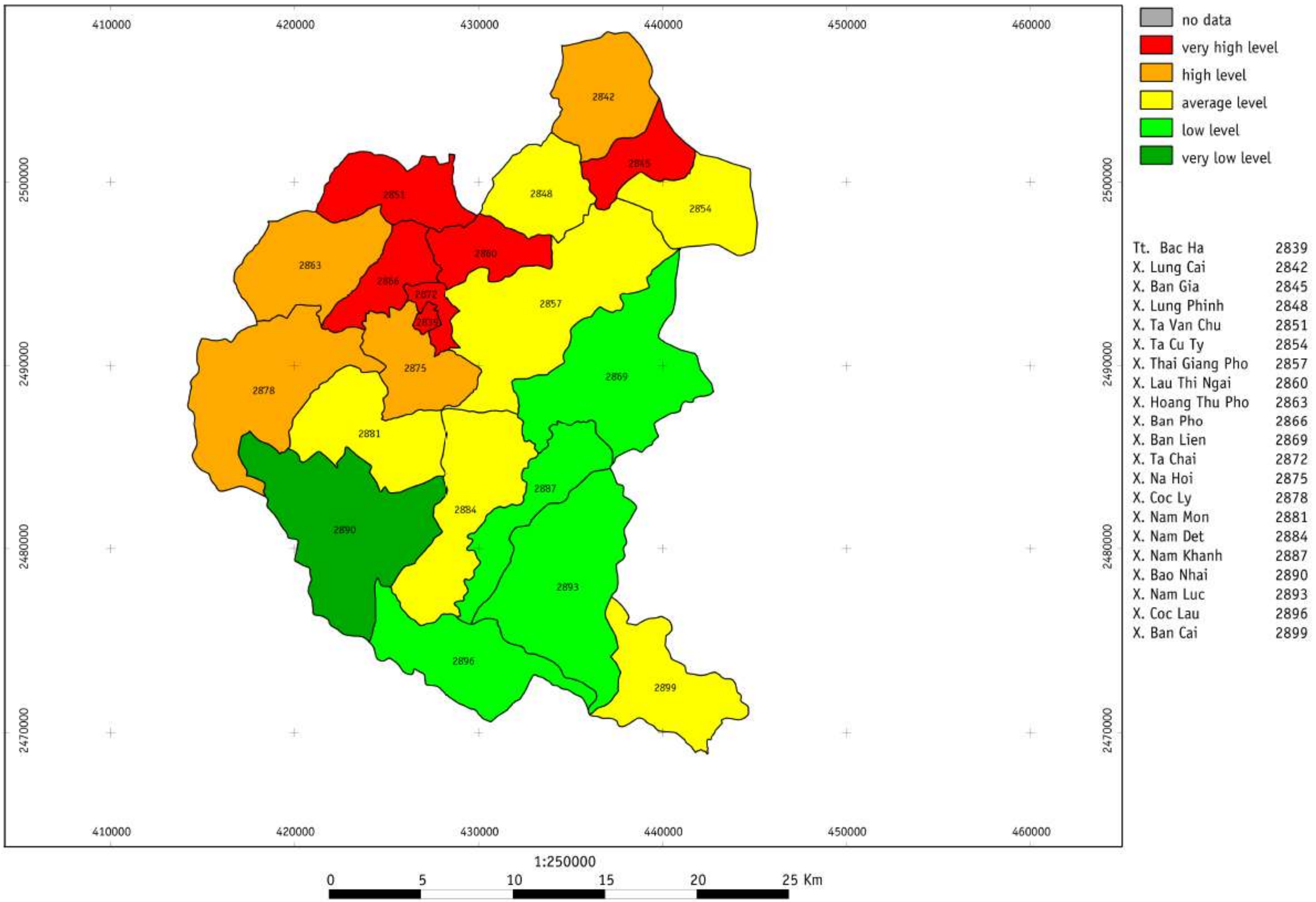
Lao Cai - Bac Ha –Wildfire' s hazard



Lao Cai - Bac Ha –Wildfire' s hazard average



Lao Cai - Bac Ha –Wildfire' s risk



Lao Cai - Bac Ha –Multihazard's risk